Light Metals 2012 *Edited by: Carlos E. Suarez*
TMS (The Minerals, Metals & Materials Society), 2012

Review on the Energy Saving Technologies Applied in Chinese Aluminum Reduction Industry

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Keywords: aluminum reduction cell, energy saving, prebaked anode cells, physical fields simulation, cell control, high quality anodes and cathodes, cell structure modification

Abstract

The energy saving technologies applied in Chinese aluminum reduction are reviewed in this paper. The energy saving technology development in China in the aluminum reduction field could be divided into three stages. The first stage was retrofit of Soederberg cells to prebaked anode cells and technology development of large amperage prebaked anode cells, which happened mainly in 1990's. The second stage was wide applications of the large amperage prebaked cell technology and the improvement of such relevant technologies as physical fields simulation, cell control systems and high quality anode and cathode manufacturing etc., which covered the first 6-7 years of this century. The third stage has lasted up to now, which mainly focused on the energy saving in the present prebaked cells by cell cathode and lining structure modifications and high performance operation and control system applications.

Introduction

China has become the biggest primary aluminum production country since 2003. Aluminum industry plays a very important role in the Chinese economic development because the huge demand for aluminum in China has driven the industry growing and expanding. More and more applications of aluminum have been found, such as the application for windows and doors in the building construction, cars and high speed trains in transportation, power supply systems and soft package etc. The proportions for various applications in China now are shown in Fig.1.

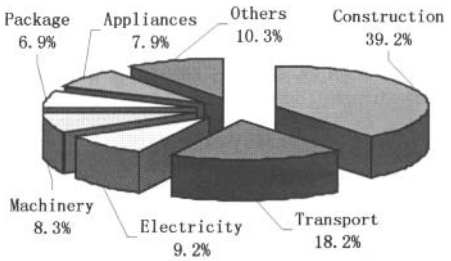

Fig.1 Aluminum applications in various fields in China

The Chinese aluminum production growth was greatly slowed down due to the global economic crisis during 2008-2009, but was recovered soon and the output reached over 16.2 million tons in 2010 as shown in Fig.2, which occupied almost 40% of the global annual yield. See Fig.3.

It is another figure for Chinese aluminum industry that the average capacity and production scale of the individual Chinese smelters has been increased quickly recently. 11 smelters had an annual capacity of more than half million tons in 2010 and totally occupied about 67% of the total primary aluminum output in China.

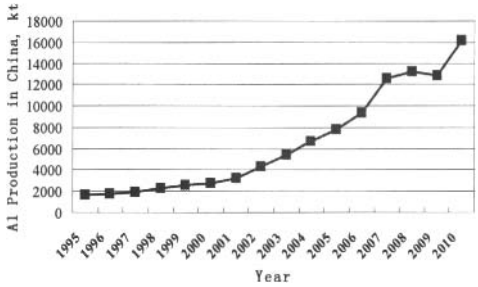

Fig.2 Aluminum production in China in past 15 years

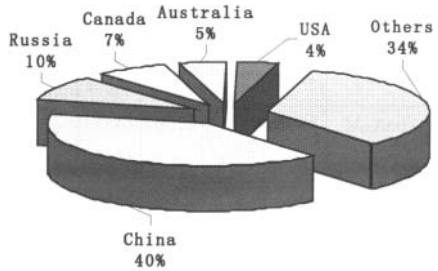

Fig.3 Production proportions for major countries in the world

The technology used in the Chinese smelters has been modernized too in the recent years. The advanced and large amperage prebaked cells are widely applied in the new smelters and being retrofitted smelters in China. About 14 potlines of 400kA were put into operation and the first 500kA potline was built in the past months and tested. Fig. 4 shows about 50% of capacity is from 300-400kA cells in Chinese smelters.

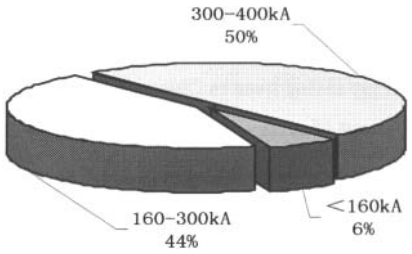

Fig.4 Cell amperage proportions in Chinese smelters

All the Chinese smelters have to be retrofitted and modernized for energy saving and higher efficiency so as to be competitive. All the capacity of the cells with the low amperage less than 160 kA were shut down before 2011 for meeting requirements of environmental protection and energy saving.

Meanwhile the smelter capacity has been transferred from the east and middle areas to the west and west-north regions, such as Inner Mongolia, Xinjiang, Ningxia, Gansu, Qinghai and Yunnan provinces etc. in China, where are rich in energy and power supply from hydro, wind and coal. About 80% of newly being built capacity and more than 50% of total smelting capacity in China is allocated in these provinces.

Chinese aluminum industry, however, is now facing lots of great challenges. The biggest challenge is energy issue including energy shortage and higher energy price.

The power supply for the most smelters in the east and middle China is from coal fire power stations. The electricity price is going up quickly because of the higher and higher coal price. The average electricity price for the Chinese smelters becomes the highest in the world smelters as shown in Table 1.

Table 1 Electricity prices for Al reduction in different countries

Countries	USA	Russia	Canada	Australia	Norway	China
Power Price ¢/kWh	1.3-5.4	1.4-3.4	0.5-3.0	1.3-2.9	1.6-3.8	4.7-9.4

The huge capacity of Chinese aluminum reduction industry arises great energy demand and has put a great pressure on the energy saving target implementation in Chinese economy. See Table 2.

Table2 Power consumption of Chinese Al reduction industry

Chinese Al industry	Unit	Years				
		2005	2006	2007	2008	2010
AC consumption/t-Al	kWh	14622	14697	14441	14323	13979
Aluminum output	k t	7806	9358	12588	13178	16195
Proportion in Chinese Nonferrous metallurgy power consumption	%	80.44	77.12	86.25	83.55	~85
Proportion in Chinese power consumption	%	4.58	4.81	5.56	5.47	~5.5

Another big challenge to Chinese smelters is low quality of alumina because of processing diasporic bauxite in most Chinese alumina refineries, which greatly impacts energy saving and current efficiency enhancing in aluminum reduction.

It is most important for the sustainable development of Chinese aluminum industry to save energy by technology optimization. This is not only for operation cost reducing and better competition capability, but also for emission reduction and implementing the government environment policy.

Energy saving issue in Chinese smelters

A great achievement of energy saving, which is mainly relied on the technology development and applications, has been made in Chinese aluminum industry in the recent years. Fig.5 shows the average energy consumption in Chinese smelters is reduced to about 14000 kWh per ton of aluminum, which is less than the world average, and about 1500kWh is saved compared with that in 2001.

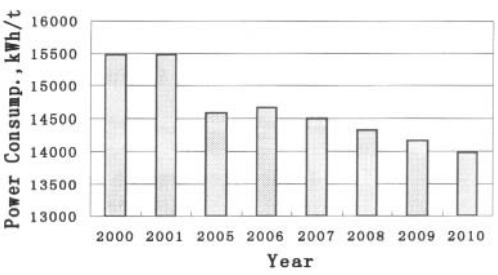

Fig.5 Energy consumption change in Chinese smelters

As mentioned above the large amperage prebaked cells are widely applied in the current Chinese smelters, which certainly benefits energy saving due to using prebaked anodes and achieving lower cell voltage and higher efficiency. So the high amperage cell design technology including the field simulation and structure modification plays an important role in energy saving in Chinese smelters.

Cell operation stability technology has been developed recently and used for lower ACD and cell voltage without current efficiency loss, which relies on the cell structure modification including cathodes, collector bars and lining structure changes.

The quality of anode, cathode and lining materials has been improved by series of manufacturing technology development, which supports high performance of the high amperage cells. Now the best quality of anodes and side wall materials in the world is produced in the Chinese manufacturers and exported overseas.

Three stages of energy saving technology in China

Three development stages can be divided in the energy saving history in China as shown in Fig.8 in the next page.

Original reduction technology level in China

The Soederberg cell technology was introduced from abroad and developed before 1980's, which was the beginning of Chinese aluminum reduction industry. There were built 8 small smelters with low amperage Soederberg cells (mostly 60kA) all over in China during 1950-1982. The DC consumption of Soederberg cell technology was as high as 14.500kWh per kg of aluminum owing to high cell voltage and low efficiency. Labor intensive and poor working conditions caused severe safety and health issues. Furthermore, its high emission of poisonous waste gas brought about serious environmental problem.

The first development stage for energy saving

The first development stage was low amperage prebaked cell stage in 1982-1995.

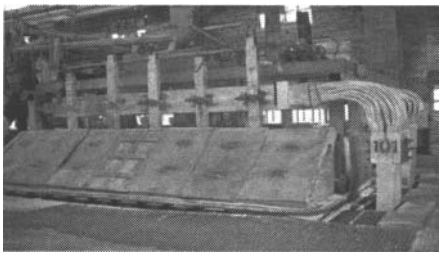

Fig.6 80 kA prebaked cell retrofitted from Soederberg cell

In this stage were included retrofit of Soederberg cells to small amperage prebaked cells (see Fig.6) and introduction of 160kA prebaked cell technology from overseas (see Fig.7) and its modification to 180kA cells

During this stage the Chinese engineers and production operators learnt the concepts on prebaked cell design, what are necessary carbon and lining materials for prebaked cells and how to operate this kind of cells.

DC consumption of 14 kWh /kg and current efficiency of more than 90% were achieved for the small prebaked cells by prebaked anode application, better cell stability and primary computer control during early 1990's. And the environment and working conditions in the smelters were relatively improved.

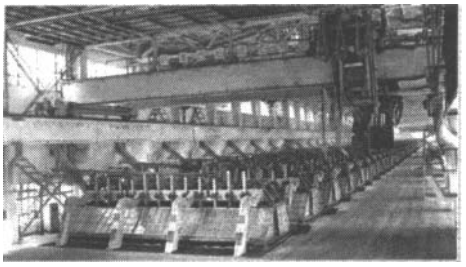

Fig.7 160 kA prebaked potline in China

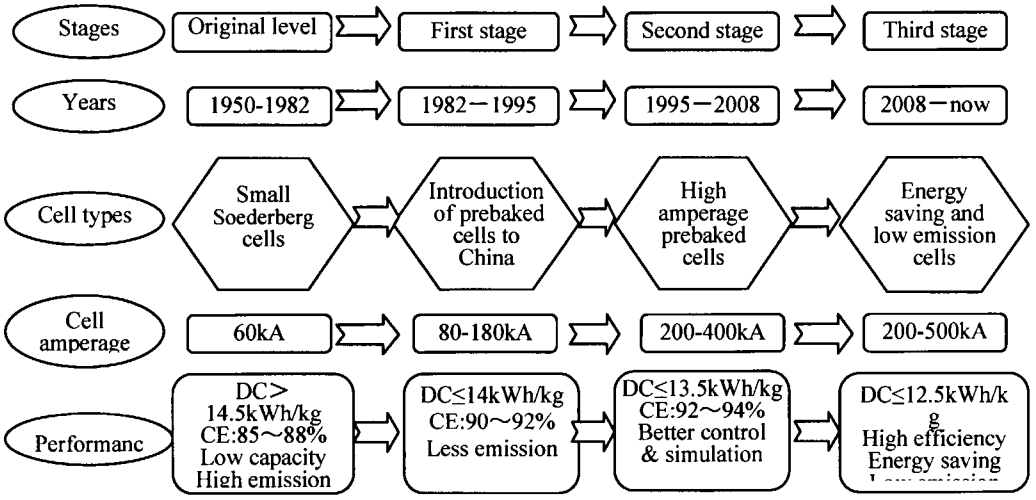

Fig.8 Three development stages of energy saving in Chinese smelters

The second development stage for energy saving

The second development stage for energy saving was high amperage prebaked cell stage in the period of 1995-2007. The industrial tests of 280kA prebaked cell technology were successfully carried out in Zhengzhou Light Metal Research Institute in 1990's, which was a milestone event indicating the Chinese engineers and scientists were capable to develop the large amperage cell technology. See Fig. 9.

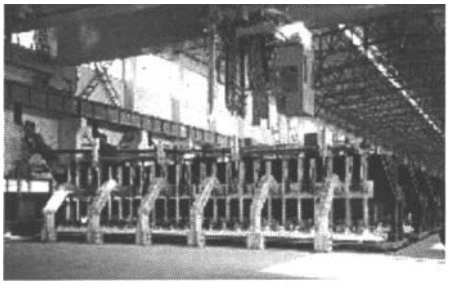

Fig.9 280kA prebaked potline in China

Since then the various amperages of large prebaked cells were designed and operated in the rapidly growing Chinese aluminum industry, such as 200kA, 240kA, 280kA, 300kA, 350kA and 400kA potlines.

With wide application of large amperage cell technology the average DC consumption was further reduced to 13.5kWh per kg of aluminum and much less emission was achieved owing to the better cell design technology, more advanced control system and developed operation technology.

During the second stage the advanced simulation & emulation software programs were introduced and applied for modifying the physical fields during the large amperage cell design and are being continuously modified in the engineering practice to meet the requirements for more complex field design and more stable operation in the larger size and stronger current cells.

At the same time the large amperage cell technology required high quality anodes, cathodes and lining materials for better performance of the cells so that the manufacturing technologies for high quality carbon and refractory materials were developed and continuously improved.

The control systems were essential to keep large cell operation stable and efficient so that various kinds of control systems, such

as so-called self-adaptive control system, fuzzy logic control system and low & narrow alumina concentration control etc., were developed and played an important role for reducing energy consumption.

As the further development of the second stage the 500kA cell technology was being developed and tested in a potline of the Chalco's Liancheng smelter recently.

The third development stage for energy saving

The applications of the new structure cell technology developed by Chinese engineers since 2008 indicates that the Chinese aluminum reduction technology for energy saving entered the third development stage.

New structure cell technology is a key technological innovation in aluminum smelting to promote energy saving. The major purpose to use this technology is to save energy by modifying the cell structure for keeping the stable operation under lower ACD and cell voltage without efficiency loss.

The structures of the horizontal installed cathode and side wall lining in the new structure cells are changed so that the fluctuation of molten metal caused by the magnetic field is greatly reduced and the CO_2 is removed quickly from anodes areas.

The new structure of the cells not only includes modification of the cathode profile shape and lining materials but also the cathode thickness and collector bar's configurations, which are of great importance to the stability and fluctuation of molten aluminum layer in the cells.

The baking and starting up technologies and a quick voltage reduction technology after cell start up for the new structure cells have been developed for successfully adapting to the special cathode and lining structure of the cells.

It is a great success that the DC consumption of new structure cells reaches about 12 kWh per kg of aluminum, which is about 1.2 kWh /kg less than the current average level of Chinese smelters.

The new structure cell technology is being applied in a big scale in more than 1000 cells of the Chinese smelters now.

Key technologies for energy saving in Chinese smelters

Large amperage cell design technology

The large amperage cell design technology is widely applied and mature design technology in China. The amperage capacity of the potlines ranges from 300 kA to 500 kA.

This technology could be supported by the advanced simulations of physical fields in the large cells, advanced cell control systems and relevant operation technologies

New structure cell technology

The new structure reduction cell technology is finding more and more applications in China and becomes the major direction of the energy saving technology.

The main features of the new structure cells are the new configurations of cathodes, collector bars and the heat preservation lining materials.

This technology could be supported by relevant design technology, high quality of carbon and lining materials, low cell voltage control systems and relative operation technologies.

Advanced control systems

Energy saving relies on the advanced and continuously improved computer control systems to a large extent.

Variety of control systems have been developed for different capacities and types of the large amperage cells in China. The control mode of the different systems, however, is similar to each other.

The major control targets are the lower and more stable alumina concentration in bath indicated from cell resistance by alumina feeding control. And the bath overheat extent is controlled by AlF_3 addition.

High quality carbon manufacturing technologies

Anode quality is very important for reducing energy consumption. A higher current efficiency and lower carbon consumption will be obtained with high quality anodes with lower CO_2 and air reactivities without much carbon sludge floating in bath, which will increase the bath viscosity and reduce current efficiency.

The key manufacturing technologies for high quality anode with the excellent properties and performance in the cells have been developed and applied in China. The manufacturing technologies for big dimension and special specification of anode have been developed and put into operation, even the anodes with slots and round edges etc can be produced.

The cathodes and lining materials with various compositions, properties and configurations can be made for the different applications.

It is owing to the manufacturing technology development of new carbon and lining materials that many advanced energy saving technologies are successfully developed.

Modified operation technology

It is required to develop lots of relevant operation technologies for adapting to the advanced energy saving technologies.

The operation technologies include energy saving baking and starting up technology, a quick voltage reduction technology after cell start up and the suitable metal tapping and anode change technologies etc.

Energy saving technology vision in the future China

Energy saving target in the future

According to the national strategic development program for energy saving in Chinese aluminum industry the average DC consumption target of less than 12.5 kWh /kg for the reduction potlines should be achieved. And a great effort will be made for the more advanced energy saving technology to achieve the DC consumption goal of 12 kWh /kg.

Further modifying high amperage cells

The high amperage prebaked cells with the capacity of more than 300kA will be dominant in Chinese smelters so as to save energy and capital cost as well. The major difficulties for this program are in following two aspects:

1. More advanced field simulation and cell structure design technology should be developed for the less molten metal fluctuation and better electrical current distribution.

2. New generation of control systems should be developed for more stable operation and more homogeneous alumina concentration distribution in the large cells.

It will be realized in the future Chinese smelters that the high amperage cells will be operated with high stability, high efficiency and great energy saving.

Further improving new structure cell technology

More and more of new structure cells will be put into operation in the Chinese smelters in the future.

The most important technological task is to further improve the structure of the cells for better performance, the major direction of which is how to coordinate the configurations of the cathodes, collector bars and cell lining for the best current distribution and as smaller horizontal current as possible.

Another improvement is to try to increase the cell efficiency under the reduced cell voltage by optimizing the smelters' operation parameters, such as bath composition, overheat control and alumina feeding mode, which are closely related to the control system improvement.

Further improving the anode quality is an essential factor for achieving the goal to obtain high efficiency. A lot of work can be done in this field.

Reducing anode effects and emission

Reducing anode effects is an important factor to save energy and to reduce emission as well. It mainly depends on the control system optimization and alumina feeding improvement.

The reasonable technical solutions should be put forward to keep alumina concentration in bath homogeneous all over the cells, which is related with the feeding system configuration and position, and the bath movement as well.

To keep excellent heat balance is also important for the constant and suitable reduction temperature, which is prerequisite to reduce anode effects.

Conclusions

1. The Chinese aluminum industry being rapidly growing is facing a serious challenge to save energy, which is very important for the sustainable development of Chinese aluminum industry in the future.
2. Three development stages can be divided as small prebaked cell technology stage including retrofit of Soederberg cells to prebaked cells, large amperage prebaked cell technology and new structure cell technology in the energy saving history of Chinese aluminum reduction industry. And the main features of the three stages are illustrated in this paper.
3. The key technologies for energy saving being applied in Chinese smelters are presented as large amperage cell design technology, new structure cell technology, advanced control systems, high quality carbon materials manufacturing technology and modified operation technology etc.
4. The energy saving target and the further energy saving vision in the future Chinese smelters are shown. The high amperage cell design technology, new structure cell technology and the technology to reduce anode effects will be further improved and up to dated for further saving energy.

References

[1] Liu Yexiang, Li Jie, *Modern Aluminum Reduction.* (Beijing, Metallurgy Industry Publishing House 2008) 90-92

[2] Qiu Zhuxian. *Principles and Application of Aluminum Reduction.* (Beijing, China Mining University Publishing House, 1998)

[3] Yao Shihuan Discussion on the Aluminum Reduction Technology Development Roadmap in China. *Chinese Aluminum Industry.* (2)(2009),. 2-14

[4] Gu Songqing, Wu Lichun, Liu Fengqin et al., *Progresses of Nonferrous Metals in China (in chinese),* (Changsha, China, Central South University Publishing House. 2007)

[5] F. Liu, S.Gu. "Study on the New Reduction Technology for Energy Saving.", *Light Metals 2010,* 387-390

[6] Liu Fengqin, Gu Songqing et al. "Application of New Structure Reduction Cell Technology in Chalco's Smelters ", *Light Metals 2011,* 509-512

[7] Li H. et al. *Technology Handbook of Aluminum Production (in chinese).* (Beijing, Metallurgy Industry Publishing House 2011)