REVIEW ON THE ENERGY SAVING TECHNOLOGIES APPLIED IN BAYER PROCESS IN CHINA

Gu S[1] and Wu J[2]

Aluminum Corporation of China Limited, No.62 Xizhimenbei Street, Beijing, China 100082
Guangxi Branch of Chalco, Pingguo, Guangxi Province, China 531400

Abstract

The energy saving technologies applied in Chinese Beyer refineries in recent years are reviewed in this paper. The Bayer process in Chinese refineries is systematically optimized by cycling efficiency improvement and liquor concentration difference reduction. A series of key technologies for intensifying the processes and reducing unit energy consumption are developed and applied, such as indirect preheating for digestion, multi-effect falling film evaporating and gas suspension calcining etc. The more efficient equipment including efficient high pressure pumps and centrifugal pumps, energy saving agitators and fans etc is widely used for lower power input. The surplus heat in the waste vapor, cycling liquor and hot solid materials in the process is more and more recovered. The application of some additives promotes energy consumption reduction. The technologies mentioned above and widely applied result in a great progress for the Chinese refineries to reduce energy consumption in the past 10 years.

Keywords: Bayer process, energy saving, cycling efficiency, intensifying process, heat recovery, efficient equipment

1. Introduction

Chinese alumina industry is still growing to meet the great demand for alumina from the Chinese smelters with huge capacity. Fig.1 shows the alumina production in China in the past years. More than 28 million tons was produced in 2010, which almost occupied 1/3 of the world production.

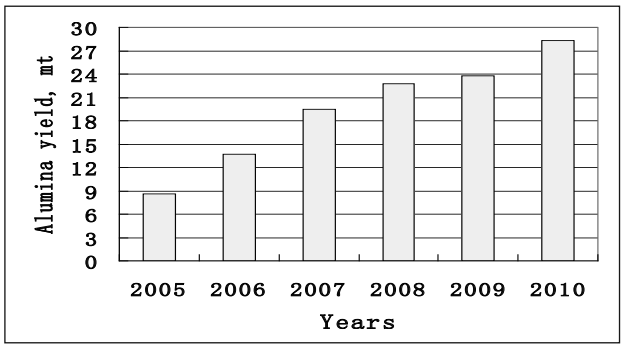

Fig.1. Alumina production in China in the past years

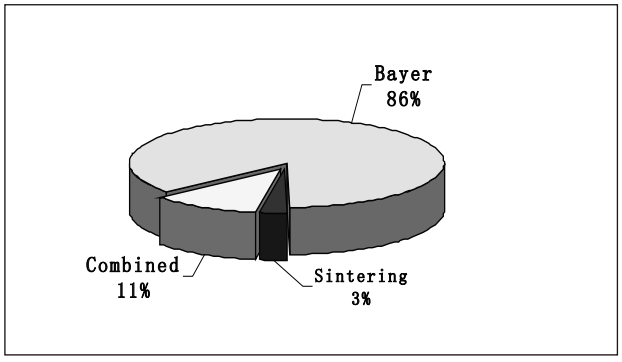

Fig.2. Production proportions of various processes in China

One of the factors for energy saving in Chinese refineries is that a great change in the process and technology used in the Chinese refineries has occurred as shown in Fig.2.

A great number of refineries applying Bayer process have been built in China since 2005, where the energy consumption reaches about 11.7 GJ per ton of alumina resulting in a gradual reduction of the average energy consumption of all the Chinese refineries. On the contrast the capacity and production of such energy intensive processes as Sintering process and Combined process were significantly cut down in the same period due to the energy price roaring. In the present the pure Sintering process only exists in two Chinese refineries and is merely for chemicals production.

Bayer process becomes the dominant technology in Chinese refineries now to treat the different kind of diasporic bauxite from the north low grade and high silica bauxite to the south high iron content bauxite in Guangxi Province.

Bayer process is carried out based on the Bayer cycle, which is mainly composed of four stages: bauxite digestion, slurry dilution and red mud separation, seeded precipitation and spent liquor evaporation. For actual alumina production operations the energy consumption is much greater than the theoretical energy consumption and a great variation of energy consumption data appears for the different minerals, which results from the different conditions and parameters in the Bayer process stages and should be systematically analyzed.

The actual energy consumption for alumina production includes not only the reaction heat in digestion, precipitation and hydrate calcination but also the energy consumed in variety of the physical processes during all the stages in whole Bayer cycle, e.g. preheating for temperature raising of slurry, evaporation for liquor concentration increase and heat loss from pipes & vessels etc.

It is essentially important to cut down the energy consumption for operation cost reducing in alumina production, especially for the high energy consumption processes.

The progress and achievements on the energy saving in the Chinese refineries are revealed and reviewed and the energy saving vision for Chinese alumina industry in the future is outlined in this paper.

Key energy saving technologies used in Bayer process in China

Theoretical study on energy saving in Bayer process

The theoretical energy consumption in Bayer process is thermodynamically analyzed for all the process reactions to evaluate the minimum energy consumption for alumina production. Thermodynamically the difference of the theoretical energy consumption for producing alumina among diaspore,

boehmite and gibbsite mainly depends on the reactions and their conditions, i.e. temperatures and concentrations etc.

Fig.3 reveals that the dissolution heat for all kinds of alumina minerals in caustic liquor is very small compared with total energy consumption in alumina production. It even becomes negative for the monohydrate when the digestion temperature is raising up to more than 250℃.

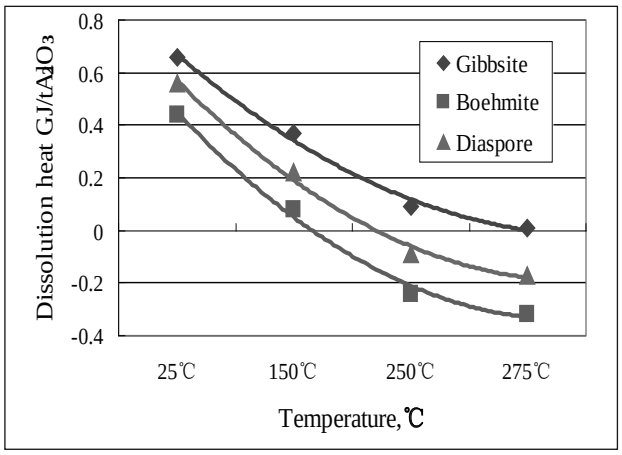

Fig. 3. Dissolution heat for different alumina minerals in caustic solution

Actually the theoretical energy consumption is less than 1 GJ in the Bayer cycle. And it is found out also by the theoretical study that the most energy is consumed for the hydrate calcinations in the alumina production, which is about 1.4 GJ per ton of alumina at 25℃ and 70% of total theoretical consumption.

Nevertheless, the practical energy consumption in the Chinese refineries is much higher and about 4-5 times of the theoretical energy consumption mentioned above. It is revealed by the detailed analysis on the energy consumption distribution in all the stages in Bayer cycle and calcination that the most of extra energy is consumed in the systematic process and efficiency loss of the processes and equipment.

A further study has been carried out on the energy consumption analysis in the systematic process including the influences of liquor concentration fluctuations by dilution and evaporation, temperature going up and down by heat exchangers and flash tanks and water balance in the process etc. A concept of the systematic energy saving is put forward based on the systematic energy study of the Bayer cycle.

Such process stages as calcination, evaporation and digestion can be identified as the highly energy consuming processes in alumina production and it is of importance to enhance the energy efficiency in the process stages.

Progresses for energy saving in Chinese refineries

The great achievements of energy saving have been made in the Chinese refineries in the past years as shown in Fig. 4.

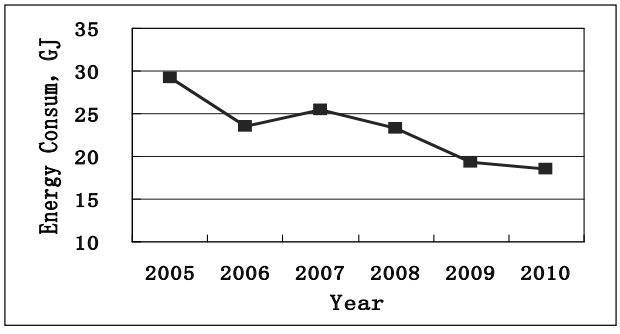

Fig.4. Energy consumption in Chinese alumina industry

The average energy consumption of Chinese refineries in 2010 was 18.5 GJ/t, which is close to the world average of about 16 GJ/t and was reduced by about 30% compared with that in 2005.

The energy saving technologies have been developed and used in the Chinese refineries mainly in the following aspects:

1. Such new processes as Flotation-Bayer process and Lime-Bayer process etc. have been developed and applied for processing high silica bauxite in the north China so that the energy saving Bayer process can be used in stead of the energy intensive Sintering and other high temperature processes to treat low grade bauxite without too much caustic loss.
2. All the procedures in the Bayer process have been intensified for higher production efficiency and productivity, such as the indirect preheating and high caustic concentration digestion and high concentration and efficient precipitation etc.
3. More efficient and energy saving equipments are applied widely in Bayer process, such as efficient deep settlers, falling film evaporators, large capacity of gas suspension calciners, large size mechanical agitation precipitators and efficient pumps and funs etc.

Key energy saving technologies used in the Bayer process in China

1. Intensifying the various stages in the Bayer process

The intensifying technologies have been developed and used in almost all the procedures in the Bayer process in China, which plays an important role in energy saving for Chinese refineries.

- Bauxite grounding and mixing proportioning: Some new crush facilities have been developed for efficient crushing of the bauxites with different properties to reduce the grinding energy consumption. The grinding process named two stage grinding with the modified grinding medium and the mill lining are used in Chinese refineries to get a suitable bauxite size distribution in the slurry, which is important for the digestion of diasporic bauxite and saving grinding energy.

- Digestion process: The indirect preheating and intensified digestion process is widely applied in Bayer digestion in the Chinese refineries in order to save energy and improve digestion efficiency. The key points are to preheat bauxite slurry to reasonably high temperatures by indirect preheating process and to keep the high temperature bauxite slurry for enough retention time. The digestion efficiency can be improved by proper bauxite size distribution, digestion temperature and time, caustic concentration and equipment improvement. For the single stream intensifying digestion process energy consumption can be greatly reduced by retarding scaling process on the preheating surface, fast switching to the spare preheaters when heat transfer efficiency is reduced, and fast and efficient scale cleaning as well. The scaling process in the single stream digestion could be retarded under the conditions of slurry flow rate control, preheating device design optimization and temperature difference scheme between the both sides of heating surface, lime addition modification and process desilication tank configuration at some temperature stages etc.

- Red mud settling process: With the higher liquor caustic concentration the solid content for the red mud settling becomes greater to bring about slower settling speed and worse underflow compactibility. So the modifications for the better settling performance have been carried out for higher efficiency including the application of the deep thickeners, new flocculent suitable to high solid content separation, self dilution of inlet slurry by overflow and raising up the settling temperatures for reducing the slurry viscosity. For the too

high solid content slurry the efficient filtration processes could be considered to use.

- Precipitation process: The technology development is focused on in the Chinese refineries to increase the productivity and to produce sandy alumina in terms of the precipitation process. The high caustic concentration precipitation is applied for less evaporation and energy saving. In order to achieve the goals and ensure satisfying productivity more complex precipitation process and finely adjusted parameters have been developed and implemented. The efficient additives and such equipment as the large volume precipitators and efficient stirs etc. (see Fig.5) are used for energy saving and better results of the hydrate properties.

Fig.5. Precipitators of 4500 m3 with advanced mechanical agitators

- Evaporation of spent liquor: The evaporation is an energy intensive process and has been modified for higher heat exchange efficiency and less fresh steam consumption in Chinese refineries. The multiple falling film evaporators including the tube type and plate type are widely applied for as low fresh steam consumption as 0.25-0.3 tons per ton of water evaporated. The heat in condensed water after evaporation is recovered partly for boiler supplemental water. Some scale retardant agent is tested and applied for reducing scaling and enhancing heat exchange in the evaporators.

- Calcination of alumina hydrate: The practical energy consumption in calcination is about one third of that in the Bayer process. Various fluidization processes, e.g. so called gas suspension calcining, and relevant equipment are applied for alumina calcination in all the Chinese refineries now and the calcining energy consumption is reduced to about 3.1 GJ. The new refractory materials are used for easier calciner maintenance, less heat loss and longer calciner life. And some heat exchangers are installed to heat hydrate washing water for the surplus heat recovery from the emitted waste gas and alumina discharged.

- Energy saving in the supplemental processes and facilities in the Chinese refineries: A great lime addition is required for diasporic bauxite digestion and the energy consumption for lime roasting occupies about 10% of total consumption in Bayer process. The new lime kiln structure, lining materials and control system are developed for more efficient lime roasting and lower energy consumption. Some cheaper fuel is tested for lime roasting for energy cost reduction. Another key supplemental facility for energy saving is the gas generators, which are very popular to be the energy source for calcinations in the Chinese refineries. The most important energy saving technology developed recently for gas generators is the waste heat recovery from the gas generated for fresh steam generation by the surplus heat boilers.

The multistage application of the steam generated in the boilers: A series of technologies have been developed and applied for efficient utilization of the steam from boilers, one of which is the optimized combination of power generation and the steam used for high temperature digestion. The efficient energy utilization of the different pressure vapors and the condensed hot water from the flash tanks and heat exchangers has been studied and the optimized technical solutions for energy saving and better heat recovery are put forward and realized in the production in some Chinese refineries.

2. Process bottlenecks hunting and optimization

There usually exist some bottlenecks in the Bayer process, especially in the old refineries and expanded projects, where some facilities are fully operated for the whole process circuit balance. Therefore the bottlenecks will possibly occurred in the stages to control the further process improvement. So the analysis on the process bottlenecks and developing the relevant technology to solve the problem are of significance for a stable and efficient Bayer process and energy saving.

The process bottlenecks can be cleared up by the following ways: reducing flow rate, expanding the equipment capacity in the stage and optimizing the technology and facilities. What happens often in the Chinese refineries is to develop and apply the key technologies for optimization of the whole process without the productivity loss. The intensifying technologies in the various stages mentioned above are the suitable selections to clear up the bottlenecks.

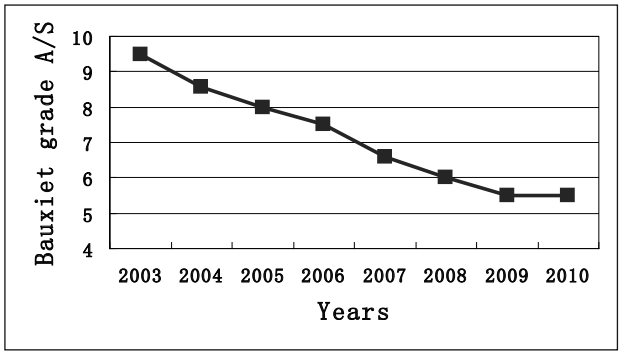

Fig.6. Bauxite grade reduction for the northern refineries in China

Since bauxite grade for the northern refineries in China is gradually reduced as shown in Fig.6 the solid content in the digested slurry is increased to change the red mud settling process to the bottleneck in Bayer process. A series of optimized settling technologies have been applied in the Chinese refineries for removing the bottleneck, such as self-dilution technology by part of the settler overflow, modified flocculant application and retrofitting the normal large diameter settlers to the deep efficient settlers for high solid content underflow to reduce washing water and energy consumption.

The liquor caustic concentration is increased recently in Bayer cycle in the Chinese refineries for higher productivity and the evaporation process becomes possibly the bottleneck in Bayer process due to higher evaporation strength and more serious scaling problem. The technologies have been developed and applied in the Chinese refineries, such as the technologies of the scale retardant additives for less scaling, tube and plate falling film evaporators for higher heat efficiency and high caustic concentration precipitation for less evaporation and saving energy.

3. Utilization of efficient and energy saving equipment

The energy saving is usually realized by equipment improvement and higher efficiency equipment application for better electrical efficiency, higher heat transfer efficiency and heat utilization rate and reducing scaling impacts etc. in the Chinese refineries.

The high efficiency equipment, such as the efficient high pressure pumps, grinding mills, centrifugal and vacuum pumps, mechanical agitators and fans with frequency changer etc. are preferentially selected in Chinese refineries for higher electrical efficiency and power energy saving.

The operation rate of the principal equipment and facilities used in Bayer process is essential to energy saving. The key factor to impact the operation rate is the scaling problem and unusual damage of the equipment or its parts in operation. In recent years the operation rate in Chinese refineries has been much increased by the process optimization, reliable equipment application and materials improvement due to less scaling and maintenance and longer operation life. The higher the operation rate is the less energy will be consumed by longer operation cycle and less on-off operations resulting in heat loss.

4. Improvement of heat utilization and waste heat recovery

Bayer cycle is a temperature changing cycle, in which the slurry or liquor flows are often heated and cooled for keeping processes going on. Meanwhile, a lot of energy is consumed and can not be fully recovered. So improving the heat exchange efficiency when the flows heated and enhancing heat recovery when the flows cooled will result in energy saving. And the heat loss from the facilities and equipment should be paid attention and reduced by better thermal insulation materials application for high temperature vessels and pipes.

The heat exchange efficiency in the heating process is closely related to scaling problem on the heating surface too. Some technical solutions have been given in the Chinese refineries including the scale retardant addition and process modifications etc. But a reliable solution in the practical operations is possibly to rapidly switch off the scaled facility by a spare facility and rapidly cleaning up the scale for switching on again.

The efficient heat recovery from the flash tank vapor, hot condensed water, high temperature liquor and solid materials results in energy saving. The liquor or slurry to be cooled and the condensed water from heat exchangers contain a great amount of heat energy, which has to be recovered by heat exchangers or directly used for boiler. The surplus heat in the emitted gas and hot solid materials from calciners and lime kilns is recovered in the Chinese refineries by heat exchangers for heating water. And the hot gas energy from the gas generators is used for generating low pressure vapor.

The significant goals for energy saving are achieved by better energy recovery, higher transfer efficiency and less heat loss for all the stages in the Bayer process in many Chinese refineries.

Energy saving technologies in Chinese refineries in the future

Challenges and tasks for energy saving in Chinese refineries

Compared with the world refineries the Chinese alumina industry has a long way to go to further save energy even though a great progress of energy saving has occurred in Chinese refineries in the past years.

With the further bauxite grade reduction the process efficiency becomes lower and the energy consumption is going up. The constantly going up energy price in China will impel the Chinese refineries to look for more energy efficient processes and equipment. The more serious competition in the domestic alumina market in the future will bring about higher risk resulting in enhancing development of the low cost and low energy consumption production technologies since about 40% of the operation cost is for energy in Chinese refineries now.

The energy saving target has been set up as less than 17.5 GJ per ton of alumina in 2015, which is reduced by 1 GJ compared with that in 2010.

Energy saving technologies in Chinese refineries in the future

The energy saving technology used in Chinese alumina industry in the future is predicted and outlined as followings.

1. Capacity scale and facility dimensions enlargement

Big production capacity, high flow rate, large diameter pipes, tanks and key equipment will be wider and wider applied in the Chinese refineries.

The average capacity of the individual refineries will be expanded in the following years to 2-3million tons of alumina instead of the current 1.5 million tons because most refineries under construction and being retrofitted have the capacity of more than 2 million tons.

The bigger dimensions of the facilities will be designed for higher flow rate and preheating surface, more retention time, less heat loss and longer operation life. For example, the diameter of the outside pipe for the vapor flow in the digestion preheaters will be expanded to more than 600 mm, in which there will be 3 or 4 inner pipes for the slurry flow with a diameter of more than 200 mm. In this preheating system a slurry flow rate as high as 800 m^3 per hour will be permitted.

2. Improving process cycling efficiency and productivity

Based on the theory of systematic energy saving improving process cycling efficiency and productivity in Bayer process is a key approach to save energy. And all the factors impacting the energy consumption are closely related to the Bayer cycling efficiency and productivity at all the stages.

It is concluded that the best ways for achieving the goals of the high efficiency and energy saving are increasing caustic concentration and A/C in pregnant liquor, relatively reducing A/C in spent liquor and decreasing the concentration differences between pregnant and spent liquors as much as possible.

The technological solutions to improve Bayer cycling efficiency and productivity in the various stages can be described as follows and possibly implemented in the next years in China.

- Increasing A/C in the pregnant liquor

Increasing A/C in pregnant liquor as much as possible is the most important technological solution for improving Bayer cycling efficiency, precipitation productivity and alumina quality as well.

Relatively high A/C can be obtained by intensifying digestion process including suitably raising up digestion temperature, increasing digestion time and caustic concentration. There is some trade off between digestion energy consumption and productivity caused by temperature raising up.

Some kind of precipitation might occur in the red mud washers, which should be alleviated to make A/C of pregnant liquor entering precipitation process as close to that of the liquor in bauxite slurry after digestion as possible. The possible way to reduce A/C difference between both liquors is to elevate red mud washing temperatures.

Sweetening process is an effective solution for higher A/C in pregnant liquor and higher precipitation productivity and can be used in the refineries with high temperature digestion and gibbsitic bauxite resource.

- Reducing A/C in spent liquor

Reducing A/C of spent liquor is a key factor to improve cycling efficiency and digestion productivity, which mainly depends on the higher precipitation efficiency and reduced hydrate suspension in spent liquor after hydrate filtration.

Relative reduction of the final precipitation temperature, suitable seed addition and the better seed agglomeration control will lead to a higher precipitation efficiency and the reasonable hydrate size distribution, which will be the major technology used in the Chinese refineries in the near future.

There is a great potential to reduce hydrate suspension from 2-5 grams per liter to less than 1 g/L in the filtrate from hydrate filtration. It will make some contribution to increasing alumina recovery and reducing A/C in spent liquor.

- Optimizing liquor concentration system

Optimizing the liquor concentration system design is greatly beneficial to improving process cycling efficiency and the productivity at main stages in Bayer process. Some Chinese refineries are trying to increase the caustic concentration in digestion up to 250 g/L for the cycling efficiency up to more than 160 g/L. It is a success and will be introduced to other refineries.

At the same time to increase the caustic concentration in Bayer digestion a higher precipitation concentration has to be required for reducing energy consumption in the evaporation, which will possibly have the negative impacts on precipitation and some technical solution should be provided for both high cycling efficiency and good precipitation results.

It is concluded that the major technical approaches to improve cycling efficiency are as follows: applying the high caustic concentration and indirect preheating digestion; enhancing A/C in digested slurry by accurate proportioning, intensifying digestion and sweetening process; reducing A/C difference between digestion and precipitation by less red mud washing loss; improving precipitation efficiency and productivity by the process optimization. The technical description of the Bayer process with high cycling efficiency and productivity is shown in Fig. 7.

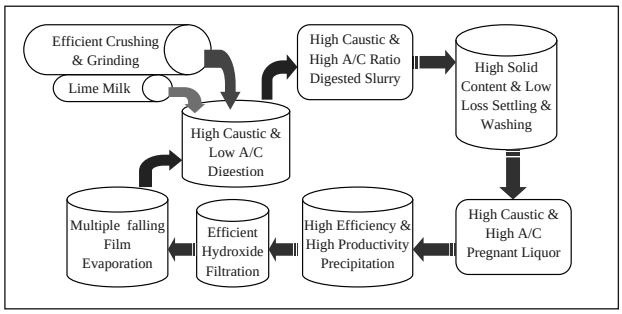

Fig.7. High cycling efficiency Bayer process scheme

3. Further intensifying the process stages and improving the heat utilization efficiency

The various Bayer process stages in the Chinese refineries have to be further intensified for energy saving including improving both the process and equipment. The best energy saving intensifying digestion process scheme is shown in Fig. 8.

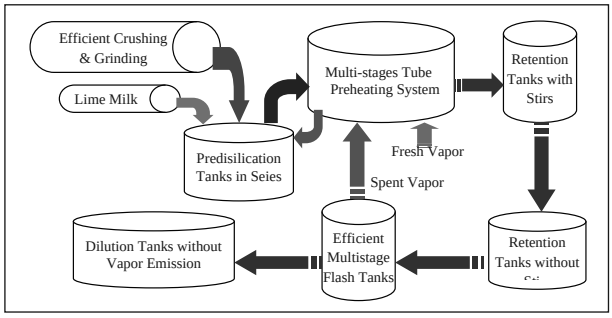

Fig.8. The best energy saving intensifying digestion process scheme

The technological features of the intensifying digestion might be the cheaper heat resource, higher operation rate, higher heat efficiency, lower power consumption, less maintenance and easier scale cleaning. The intensifying other Bayer process stages should follow the same technical routines.

The technologies to further enhance the energy utilization efficiency and heat recovery have to be developed and applied in Chinese refineries in the future. This is a topic of energy saving forever. The principles in this field can be found in the mentioned above.

Excellent water balance and more efficient filtration & washing (i.e. efficient solid separation) should be considered to reduce evaporation and calcining energy consumption. The different water flows in the refineries have to be classified and reused as much as possible and a so called zero water drainage should be realized in the future Chinese refineries.

4. Improving process online inspection and control systems

The online inspection and detecting sensors with the excellent characteristics and the advanced control systems have to be developed in order to achieve the goals of on-line testing, automatic recording, accurate adjusting and control with good performance and without much maintenance for energy saving.

The detailed possible technical innovations in this field include the accurate proportioning during bauxite slurry grinding and pumping by fast testing and control system, parameter optimization adjustment on the bauxite slurry preheating, digestion and evaporation in flash tanks; inspection and control of the liquor concentration in the whole Bayer process; slurry level control in the tanks and vessels etc.

5. Conclusions

Chinese alumina industry is growing rapidly and Bayer process becomes the dominant technology used in the Chinese refineries now.

The great energy saving achievements have been made in Bayer process in the Chinese refineries in the past years, but there still exist the great challenges and requirement for energy saving.

The key energy saving technologies used in the various Bayer process stages in the current Chinese refineries are covering the following fields: intensifying technologies in the various procedures, process bottlenecks hunting and optimization, utilization of efficient and energy saving equipment and the technologies to improve heat utilization and waste heat recovery.

The energy saving technologies which will developed and used in the future Chinese refineries are predicted as follows: the technology to expand the production capacity and facility dimensions, the technology to improve process cycling efficiency and productivity, the technology to further intensify the process stages and improve heat utilization efficiency and the technology to improve process online inspection and control.

References

[1] Gu Songqing "Alumina Production Technology with High Efficiency and Low Consumption from Chinese Bauxite Resource" *The Chinese Journal of Nonferrous Metals,* 14 (Special 1) 2004, pp.91-97

[2] Qi Lijuan, Gu Songqing Wang Qingwei. "Comprehensive Energy Saving in China Alumina Industry" *Light Metals* 2005 p.35-40

[3] K. Solymar et al. "Co-processing of Different Types of Bauxite with High Efficiency" *Light Metals,* 2001, p.105

[4] Gu Songqing et al. "Energy Saving in Bayer Process ", *Light Metals,* 2007

[5] Gu Songqing "Study on Productivity and Efficiency in Bayer Process" *Proceedings of ICSOBA,* India, 2005