

## **The Evolution of Alumina Production Technology in China, New Challenges and Trends**

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### **Abstract**

Great progress in alumina production technology has been achieved by the Chinese alumina industry in three development stages in the past 63 years. The first development stage was implementation of the Sinter and Bayer-Sinter combined processes to treat diasporic bauxite. The second stage was the wide application of the Bayer process for Chinese diasporic bauxite. The third stage has been the adaption of technology for processing medium and low grade Chinese diasporic bauxite based on the Bayer process. The greatest achievements in these stages include implementation of high capacity tube digestion, bauxite beneficiation for silica and sulfur by flotation prior to the Bayer process, high lime addition, and generally increased efficiency and productivity in the Bayer process. Now a series of major new challenges have emerged, where diasporic bauxite with high organic and high sulfur content has to be processed cost effectively, high energy and caustic consumptions have to be reduced, and the utilization of bauxite residues has to be improved. The major assumptions and possible technical solutions for the new challenges are discussed in this paper.

**Keywords:** China, alumina, Bayer process, sulfur, organics, energy, bauxite residues.

### **1. Introduction**

About 61 million tons of alumina was produced in China in 2016, constituting over 53% of global production. There are 13 alumina companies with an annual production of over 2 million tons. The average production capacity for Chinese refineries is about 1.5 million tons per year.

It can be considered that Chinese alumina production technology has been developed in three major stages over the last 63 years. The Shandong refinery was the first commissioned using the Sinter process in 1954. Following this, the Bayer-Sinter combined process was developed for the local diasporic bauxite. In the recent times, the key production process has become the Bayer process following the successful implementation of high temperature and high caustic Bayer digestion for diasporic bauxite and the economic utilization of the Bayer process for medium and low grade bauxites [1].

Meanwhile, new technology challenges are confronting alumina production in a new era for the Chinese industry. These challenges include the introduction of high organic and high sulfur content bauxites bringing significant challenges to Bayer production stability and alumina quality. Production cost pressures have also increased significantly as the bauxite grade is reduced in the northern areas of China, and the prices of caustic soda and bauxite have increased. Furthermore, the security disposal and/or comprehensive utilization of bauxite residues become important and urgent since most of the Chinese refineries are located in the big population centers near bauxite mines.

New technically efficient and lower cost technology solutions are needed to meet these challenges. These future technology development requirements and trends for the Chinese alumina industry are discussed in this paper.

## 2. Evolution of Chinese Alumina Industry Technology

The Chinese alumina industry has undergone three development stages in the past 63 years.



**Figure 1. Sinter Process in Chalco's Shandong Refinery.**

The first stage was the development and application of the sinter process and Bayer-sintering combined process to treat Chinese diasporic bauxite. The diasporic bauxite reserve was explored in Henan and Shandong provinces in the 1950s. The sinter process similar to that used for cement production was applied and put into operation in the Shandong refinery since there was no Bayer technology available in China suitable for diasporic bauxite at that time.

High temperature digestion technology with direct steam injection into digesters was introduced from Russia in the 1950s, and this kind of Bayer process for Chinese diasporic bauxite was first applied in the Zhengzhou refinery in Henan. This technology had high energy consumption due to the direct steam heating. As mentioned above, the Bayer-Sinter combined process was developed in the 1960s, in which both bauxite residue from the Bayer process and low-grade bauxite were mixed with soda ash and limestone and fed into a sintering kiln. The Bayer-Sinter combined process was widely applied in many refineries such as in Henan, Shanxi and Guizhou and became the major refining process in China from the 1970s until the 1990s.



**Figure 2. Bayer-Sinter Combined Process in the Chalco's Shanxi Refinery.**

The second stage was development and application of the Bayer process with indirect

preheating for diasporic bauxite. The indirect preheating and high productivity digestion process for Chinese diasporic bauxites was a very important step for its energy savings. A great effort was made for the deployment of this technology in China in the 1980s and 1990s. The indirect preheating technology from Pechiney was introduced and successfully applied firstly in Shanxi refinery and then in Pingguo refinery in the 1990s.



**Figure 3. Tube Preheating and Autoclave Digestion in Chalco's Henan Refinery.**

In the meantime, tube digestion equipment was introduced from VAW by the Zhengzhou refinery in the 1990s but the industrial tests for this equipment were unsuccessful at the time. Consequently the Zhengzhou refinery (presently the Henan refinery) applied the tube preheating & autoclave retention tank digestion technology developed by Zhengzhou Light Metal Research Institute and successfully put it into operation.



**Figure 4. Bayer Process in Chalco's Pingguo Refinery, Guangxi.**

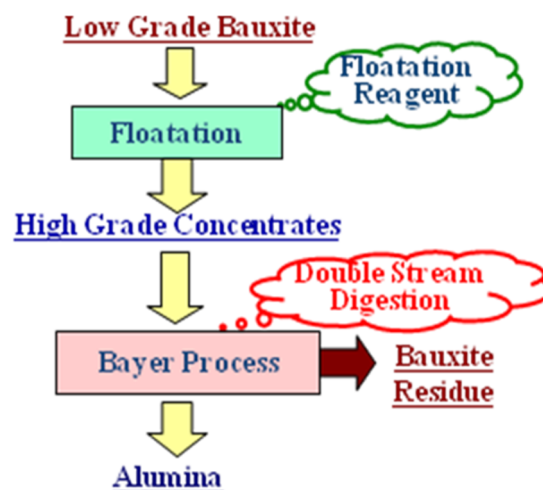
Two kinds of the indirect preheating processes mentioned above have been applied for Chinese diasporic bauxite since then.

The first pure Bayer process to treat diasporic bauxite in China was put into operation in the Pingguo refinery in 1994. As just mentioned the indirect preheating technology in Pingguo refinery was introduced from Pechiney and the design capacity was 300 kt per operation line per year.

Major technical retrofits have been made in the past 23 years in the Pingguo refinery, and the capacity per line has now increased to more than 500 kt / year and total annual production is over 2.5 million tons. The greatest technology achievement is the development and application of a high efficiency Bayer process by dramatic improvement of the Bayer cycle efficiency up to 160 kg/m<sup>3</sup> resulting in systematic energy savings and much improved yield.

Almost all the Chinese refineries set up since 1994 apply Bayer process instead of the Sinter and Bayer-Sinter combined processes. A series of key Bayer technologies were developed and/or applied in the new refineries including indirect preheating and high-efficiency digestion, high efficiency settling utilizing synthetic flocculant, falling film evaporation, fluid bed calcination, mechanically agitated precipitators etc. The technology for sandy alumina production from diasporic bauxite has been developed as well. Up until now, efficient and high productivity Bayer process technology has become the key production process in Chinese refineries for lower energy consumption, higher productivity and better alumina quality.

The third stage is development and application of the technology for processing medium and low grade diasporic bauxite based on the Bayer process [2]. Higher quality bauxite in much of China has been almost exhausted, and the bauxite grade in the north areas of China has been quickly reduced in the last 20 years. Chinese refineries faced the challenge of being short of high grade bauxite for their Bayer processes. Based on more than 10 years R&D effort, the Flotation Bayer and Lime Bayer processes have been developed and applied for medium & low grade diasporic bauxite.



**Figure 5. Flotation-Bayer Process.**

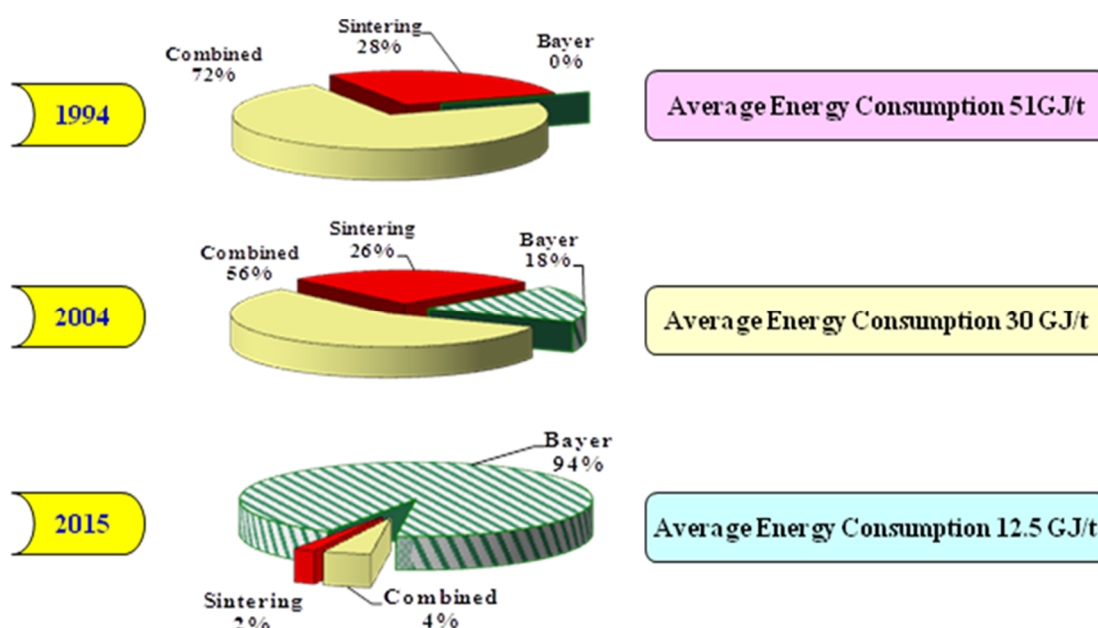
As shown in Figure 5 some silica minerals in medium & low-grade bauxites are removed by the direct flotation process. The products from flotation become higher grade and can be used more efficiently in the subsequent Bayer process. Tests shows that some illite and pyrophyllite in the low-grade bauxite is separated from diasporic by the flotation process and the alumina to silica ratio in the concentrates can be improved from 4 to more than 7, which results in a great increase in bauxite resources available for the Bayer process.

The Lime Bayer process is another technology to treat lower grade diasporic bauxite by the Bayer Process. Some cancrinite can be changed to hydrogarnet by more lime addition in the Bayer digestion process and the caustic consumption will be reduced so that the lower grade bauxite can be economically processed by the Lime Bayer process.

In recent years, a few Chinese refineries have been successfully retrofitted from the Bayer-Sinter combined process to the Bayer-Sinter process in series, in which only Bayer residue is sintered without bauxite addition for energy saving.

Some Bayer refineries have applied full tube digestion technology instead of tube preheating & retention autoclave digestion technology under the conditions of higher than 260 °C, digestion times of 40 minutes and slurry flow rates of 500 m<sup>3</sup>/hr.

Figure 6 shows the evolution of technology in the Chinese alumina industry since 1994. There were only Sinter or Bayer-Sinter combined processes with only the direct steam heating digestion from Russia before 1994. The indirect preheating technologies and a series of Bayer technologies have been introduced from Western Europe and the technologies for medium & low-grade bauxite developed so that the Bayer process becomes the major process and represents 94% of total capacity in China in 2015. Meanwhile the energy consumption has been reduced from 51 GJ in 1994 to 12.5 GJ per ton of alumina in 2015, which is approaching the world average [3].



**Figure 6. Technology Process Transition of Chinese Alumina Industry.**

The remarkable features of technology development in the present Chinese alumina industry are as follows: 1) The key process becomes the Bayer process with high temperatures, high caustic and high flow rates; 2) Medium and low grade diasporic bauxites can be treated in the Bayer process; 3) A high efficiency Bayer process is applied in Chinese refineries for energy saving and high productivity; 4) High quality sandy alumina is able to be produced in Chinese refineries [4].

### **3. Major New Challenges Being Faced by the Chinese Alumina Industry**

#### **3.1. High Organic and High Sulfur Bauxites**

Some of the Chinese bauxites used now contain high organic and high sulfur compounds, which can be extracted in the digestion process to produce organic and sulfur compounds accumulating in the Bayer process liquor and causing numerous negative impacts on production. A serious technical challenge to the industry emerges.

The organic concentration (manifested as oxalate) reaches a supersaturated level in some Chinese refineries. The effect of oxalate on the Bayer process can be mitigated by raising precipitation temperatures and lowering caustic concentration but each of these will reduce precipitation yield. It also becomes difficult to keep a stable and efficient Bayer process. For this reason (as is the case in many refineries outside China) oxalate and organic removal is becoming important to Chinese refineries.

The bauxites with sulfur content more than 1% appear in the underground bauxite mines located in north Guizhou and Henan and usually have higher A/S grade. The sulfur in these high sulfur bauxites mainly occur as pyrite. Pyrite reacts with caustic liquor to form a series of sulfur ions such as S<sup>2-</sup>, S<sub>2</sub>O<sub>3</sub><sup>2-</sup> and SO<sub>3</sub><sup>2-</sup>, etc at digestion temperatures, which results in difficulties with the settling of bauxite residues and the reduction of alumina quality. It has become urgent to remove sulfur for the refineries using high sulfur bauxites.

#### **3.2. Further Reducing Energy, Bauxite and Caustic Consumptions to Lower Operating Cost**

Compared with global best practice, the energy consumption of Chinese alumina refineries has a long way to go, even though great progress has been made in the past years. The average specific energy consumption of the Chinese alumina industry in 2015 was 12.5 GJ/t, a little higher than the world average, but still much more than the global industry benchmarks [5, 6].

It is found from the analysis of energy consumption in the Chinese refineries that the higher energy consumption due to higher temperature and higher caustic digestion is partly offset by the implementation of more efficient and high productivity Bayer technology [7].

Nevertheless, waste heat recovery and reuse have to be promoted. There remains potential to further reduce or reuse flash steam losses in digestion and recover more heat from the flue gas of calciners amongst other opportunities. The competitiveness of the Chinese industry, in part, rests on energy saving technology being further developed and deployed.

Bauxite and caustic consumptions have become the important factors to influence operating cost because the bauxite grade has been going down in the north China leading to average caustic consumptions of up to 160 kg/t as soda ash. The prices of bauxite and caustic have also increased significantly in the recent years. A new process should be developed for the processing of low grade bauxite to reduce the operation cost.

#### **3.3. Large Scale Utilization of Bauxite Residues**

The dry disposal of bauxite residues has been already widely applied in Chinese refineries, much improving containment security and reducing the caustic pollution in the residue stack areas. With the fast growth of Chinese alumina production, about 100 million tons of bauxite residues are produced per year in China. It is urgent to develop technology for large scale utilization of bauxite residues instead of only storage.

The major opportunities for large scale utilization of red mud would be in the industry fields of iron and steel manufacturing, construction and environmental improvement because such compounds containing Fe, Si, Al and Ca etc in the residue could be reused in these fields [8].

#### **4. Technology Development Trends for the Chinese Alumina Industry**

To meet the challenges in the next 5 years, the major goals in technology development for Chinese alumina industry may be presented as the following four objectives:

- 1) Eliminating the detrimental effects of organics and sulfur in bauxite on the steady and efficient operation of the Bayer process;
- 2) Developing technologies for the processing of low grade diasporic bauxite at lower operating cost;
- 3) Improved energy savings from waste heat recovery;
- 4) Developing 1-2 large scale bauxite residue utilization technologies for high value added products.

The technical solutions to achieve the goals are discussed in the following important 7 projects:

##### **4.1. Organic Removal from Bayer liquor**

As is well understood by the industry outside China, oxalate is one of the most harmful organic substances. A significant challenge has appeared recently in Chinese refineries due to the arrival of oxalate supersaturation in Bayer liquor, which results in fine product size distribution, reduction of precipitation productivity, scale formation and difficulty in controlling the precipitation process.

The major technical solution for oxalate removal from Bayer liquor is to develop and/or implement a crystallization process to remove sodium oxalates from Bayer liquor in either the precipitation area or following the evaporation process. Sodium oxalate crystallization and separation from the streams at lower temperatures looks an interesting option at lower operating cost, considering the high spent liquor caustic concentration after precipitation and evaporation in Chinese refineries.

##### **4.2. Sulfur Removal from Bauxite**

Studies show that the anions of sulfur, thiosulfate etc., from the reaction of pyrite with Bayer liquor can chelate with iron ions in the liquor to form unstable complexes, resulting in iron containing hydrate precipitating in the precipitation process to produce higher iron alumina product. There is also the potential for significant corrosion of steel equipment by some kinds of sulfur species.

The initial technology employed in China to remove sulfur from these high sulfur bauxites was the flotation process, which in practice results in incomplete removal. A more efficient approach is low temperature oxidation by bauxite roasting, which has been patented in China. The pyrite can be oxidized above 500 °C during bauxite roasting, where organics and water are removed as well as sulfur. The roasted “clean” bauxite contains no sulfur, organic or crystallized water and can be used in the subsequent Bayer process with higher efficiencies. Some consumption of energy is obviously required for the oxidation roasting, which is partly offset by the heat released during the exothermic pyrite oxidation.

#### **4.3. Caustic Recovery from High Caustic Residues by Hydrometallurgical Processes**

High caustic content Bayer residue will be produced by the Bayer process when treating low grade bauxite. Caustic contents in the residues sometimes reach to as high as 10%, which would lead to high caustic consumption and unacceptable production cost.

The best way to meet this challenge is to develop a hydrometallurgical process to recover caustic and alumina from the Bayer residues. Test work shows that under suitable conditions, Bayer residue can react with additives in the caustic solution to form low caustic and alumina content hydrogarnet. Most of the caustic soda and part of alumina in the Bayer residues can be recovered and returned to the Bayer process. This is an energy efficient process to efficiently recover value from Bayer residue.

#### **4.4. Optimized Recovery and Reuse of the Steam from Digestion and Evaporation**

High temperature and high caustic digestion and evaporation processes are adopted in all Chinese refineries to treat local diasporic bauxite. The bauxite slurry and the liquor to be evaporated are usually preheated by flash steam in the early stages. It is a key objective in energy efficiency to sufficiently recover this heat during the heat exchange process. The waste heat in the fresh steam condensate is able to be reused in several stages until it is no longer efficient to recover heat and becomes boiler feed water.

#### **4.5. Reuse of the Waste Heat from Calcination**

Not only lots of sensible heat but also large amounts of potential heat exist in the high temperature exhaust gas of calcination due to the large amounts of water vapor in the gas. It is very important to fully recover both sensible and potential energy in the waste gas. Should the waste gas temperature be reduced to less than 100°C all the water vapor will be condensed and the potential heat recovered. The technical challenge is to recover this heat economically, while avoiding corrosion of the heat exchange equipment by the acidic solution due to sulfur content in the gas.

The discharges from alumina calciners and lime kilns are often at the temperatures of higher than 200°C, which should be reduced to less than 100 °C for subsequent handling. This kind of waste heat can be recovered by an air heat exchanger and reused in wash water heating.

#### **4.6. Reuse of High Iron Bauxite Residue in the Iron and Steel Industry**

Bauxite residues with over 35% of Fe<sub>2</sub>O<sub>3</sub> are produced in the refineries located in Guangxi and Shandong provinces, and more than 40 million tons of these kinds of the residues are disposed in every year. Large scale iron & steel operations usually exist near these refineries in China and the obvious opportunity is to reuse these bauxite residues in the iron & steel operations nearby [9].

It is proposed that concentrates with about 55% iron content can be produced by high gradient magnetic separation of the residues, and used to supplement the feed to iron smelting. Bauxite residue can also be utilized as the flux component in the steel refining.

#### 4.7. Reuse of Bauxite Residue in Environmental Protection Applications

Bauxite residues can be used to treat acidic waste water from flotation tails and other nonferrous metals metallurgical wastes, city river sludge, acidic waste residues from other industries, acidic soil as well as the waste gases containing SO<sub>2</sub> owing to their caustic content

Such harmful metal elements as Cr, Pb and Cu can be adsorbed by the bauxite residues because of their high specific surface areas and mineral structures. This is why the bauxite residues are useful for acidic soil amendment. Furthermore, bauxite residues contain many other elements such as Al, Si, Na, Fe and Ca etc, which can be used for inorganic flocculants and agents for environmental management [9].

#### 5. Summary

Three important development stages have been undergone for the Chinese alumina industry: 1) Development and application of Sinter and Bayer-Sinter Combined processes for Chinese diasporic bauxite; 2) Development and application of Bayer process with indirect heating for diasporic bauxite; 3) Development and application of the technology for the medium and low grade diasporic bauxite based on Bayer process.

The Chinese alumina industry faces three new great challenges: 1) High silica, high organic and high sulfur content bauxite to be treated by Bayer process; 2) Further reduction of energy, bauxite and caustic consumptions at lower operating cost; 3) Greater utilization of bauxite residues on the large scale.

The technology development trend for Chinese alumina industry is as follows: 1) Eliminating the hazards from organic and sulfur in the bauxite for the steady and efficient operation of Bayer process; 2) Developing an energy saving and efficient process with low operation cost for the low grade diasporic bauxite; 3) Realizing greater energy savings by waste heat recovery; 4) Developing 1 - 2 large scale bauxite residue utilization technologies for high value-added products.

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