Study on the predicament and sustainable development of the alumina smelting industry in China

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Abstract: On the basis of a comprehensive review of the production and technology status of China's alumina industry, the main contradictions and challenges in the development of China's alumina industry in terms of resources, energy and environmental governance are analyzed, and the production cost is compared and analyzed worldwide. It is believed that the main factors restricting the sustainable development of alumina industry in China are the lack of sufficient high-quality bauxite resources in China, the production technology needs to be further optimized, and the generated solid and hazardous waste is difficult to realize harmless and resource utilization. In this regard, this paper puts forward the strategy for the sustainable development of China's alumina industry, that is, strictly control the disorderly and rapid expansion of production capacity and reasonable layout, optimize the resource and energy supply structure, implement the industrial development strategy of high quality, energy saving and low consumption to improve the core competitiveness, and accelerate the realization of the standard discharge and resource utilization of waste gas, wastewater and solid waste. The results of this paper are of great significance to the strategy of industrial structure adjustment and sustainable development of alumina industry in China.

1. Introduction

China's rapid economic development has promoted the strong demand for aluminum, which has strongly promoted the rapid development of China's alumina industry. Through the digestion and absorption of imported technologies and independent scientific and technological innovation, a pattern of common development of various forms of ownership has been achieved, a complete alumina industrial system has been formed, and China has become the world's largest aluminum production, consumption, import and export trading country. In 2022, China's alumina reached 81.862 million tons, accounting for 56.61% of the global alumina production. The technological innovation and scientific and technological progress of China's alumina oxide industry have also made remarkable achievements.

However, the huge scale of alumina industrial production has led to increasingly prominent resource, energy and environmental issues. Especially in recent years, due to the significant increase in domestic alumina production, environmental protection and other policies, domestic bauxite resources have been difficult to meet the demand, the proportion of imported bauxite resources has increased year by year, and the external dependence of bauxite has exceeded 60%[1]. The solid waste produced by alumina industry is increasing year by year, which has caused great pressure and impact on the ecological and environmental protection..

In view of the serious constraints on resources, energy and the environment, as well as the limits of the market development capacity, the development and survival of China's alumina industry has reached a very critical period. Carefully study the production and technology status of China's alumina oxide industry, analyze the main contradictions and challenges facing the development of China's alumina oxide industry, compare and analyze the production cost competitiveness on a global scale, and put forward the strategic development trend of China's alumina oxide industry production and technology. This is of great significance to the strategic research of industrial structure adjustment and high-quality sustainable development of China's alumina industry.

In this paper, the second part introduces the relevant research literature, the third part analyzes the production and resource status of China's alumina industry, the fourth part analyzes the production technology status of China's alumina oxide industry, the fifth part. The advantages and disadvantages of China's alumina industry are analyzed, the sixth part puts forward the relevant strategies and suggestions for the sustainable development of China's alumina smelting industry, and the seventh part puts forward the conclusion.

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2. Research on the development of alumina smelting industry

2.1. Research on the alumina smelting technology

According to Yin Keting (1996), the production process of alumina in China is complex, the process is long, and the energy consumption is 1-3 times higher than that of foreign countries. Resource extraction is poorly managed and seriously wasted [2]. Liao Zhihua (2020) believes that the disorderly development of alumina industry will lead to overcapacity and vicious competition. The large proportion of bauxite imports and the high concentration of import countries will bring uncertain factors [3]. Ma Lifang (2019) believes that the transformation and management experience of cleaner production of alumina not only effectively solve the environmental protection problem, but also obtain better economic benefits [4]. Zhang Qingxuan (2018) believes that effectively reducing energy consumption in alumina production and realizing sustainable development of energy conservation and environmental protection are issues that alumina production enterprises must attach great importance to [5]. Li Zhuozhi (2017) proposed that the innovation of alumina smelting technology would play a positive role in improving red mud treatment technology and promote the healthy and sustainable development of China's economy [6]. Xue Shengguo et al. (2017) found that resource utilization and large-scale disposal of red mud in thesolidification rate smelting process played a positive role in environmental risk prevention and control management and promoting the healthy development of alumina industry [7]. Yue Ling (2015) believes that China's alumina enterprises should actively explore overseas markets, develop and occupy overseas bauxite resources, and ensure the sustainable and stable development of China's alumina industry [8].

2.2. Research on the sustainable development of alumina industry.

Che Junwen et al. (2018) believe that the alumina industry is a resource, capital and technology-intensive raw material industry. Due to the large amount of tailings and red mud produced in the production process, a certain amount of alkali-containing wastewater is generated in the production process of alumina, resulting in very serious water pollution. Therefore, water pollution in the alumina industry has the most serious environmental impact [9]. Hao Haizheng (2019) believes that for the sustainable development of bauxite resources in Laos, along with the development of alumina industry, environmental protection has become the focus of the industry. Therefore, in the promotion of aluminum ore dressing technology, industry managers should recognize the value of ecological environmental protection and comprehensive utilization of resources. Implementation of green industrial development projects [10]. According to Xu Bin (2018), for resource-based enterprises, the upgrading of industrial pattern can improve the comprehensive utilization rate of resources and reduce production and manufacturing costs. Through systematic technological innovation and optimization, the comprehensive utilization rate of resources is constantly improved and the manufacturing cost of the whole industrial chain is reduced [11]. Zhou Faxing (2018) found that the most important measure to reduce energy consumption in alumina production is to update and reform production technology, seeking to meet the purpose of energy saving and consumption reduction while improving work efficiency. In addition, the quality of the raw materials used is strictly controlled, and the performance of the finished alumina products is committed to improving, so as to stand out in the same type of goods [12]. Wang Ning (2018) believes that alumina enterprises continue to improve their own production technology, reduce environmental pollution and excessive energy consumption, and achieve harmonious social and economic development [13].

Shao Ke (2023) believes that the improvement of resource utilization efficiency can not only reduce manufacturing costs and improve production efficiency, but also reduce the dependence on limited resources, reduce the impact on the environment, and promote the sustainable development of industrial economy [14]. Zhan Jianren (2023) believes that in the practice of industrial economic development, in order to further promote the economic development of the region, it is of significant value for regional development to think deeply about the sustainable development strategy of industrial economy under the new situation [15]. Huo Zhihong et al. (2022) believe that the standardization and mobility of low-carbon technology can promote the transfer and sharing of carbon reduction technology, and its upgrading process will promote the transformation of regional industrial economy to the low-carbon sustainable development path of "deindustrialization" and "modernization" [16].

2.3. Research on the influence of the new energy on the sustainable development of alumina industry.

Du Songqing (2019) believes that new energy plays an important role in structural transformation, and the development of new energy can drive regional economic development [17]. Jin Shuaiyu (2017) believes that China's energy development is faced with such problems as the increasingly exhausted exploitation of non-renewable resources, the slow development of renewable and clean energy, and the need to improve energy exploitation technology [18]. Xu Meiling et al. (2017) believe that under the environment of low-carbon economy, the research and development of new energy technologies effectively promotes the development of low-carbon economy [19]. Lin Yong (2023) believes that with the increasing market share of renewable energy, technology transfer has become the focus of attention of the international community [20]. Cao Li et al. (2017) believe that technology is the guarantee for the development of low-carbon economy, and the
development of new energy sources and research and development of new energy technologies are of great significance to promote the development of low-carbon economy [21].

3. Analysis of the production and resource status of alumina industry in China

Most alumina production enterprises are located in the regions of China with rich bauxite reserves, namely Shanxi, Henan, Guangxi and Guizhou. Alumina enterprises in Shandong Province, due to its proximity to the coast, mainly rely on imports of bauxite to produce alumina.

3.2. Analysis of the bauxite resources

According to the report on China's mineral resources released by the Ministry of Natural Resources in 2019 [22], in 2018, China's bauxite resources amounted to 5.17 billion tons, but its proven reserves were only 1 billion tons, accounting for only 3.3% of the world's reserves, which is far lower than Guinea, Australia, Brazil, Vietnam and Jamaica [23]. See Figure 2.

Therefore, in the world, China's bauxite reserves are relatively small, and the bauxite that can be economically utilized is all refractory diaspore ore, and the grade is low. Shanxi, Henan and other regions in northern China have a large number of large-scale aluminum oxide plants, and the distribution is concentrated. Due to decades of excessive mining, the local bauxite mining grade decline, serious depletion, and even depletion, the current supply of aluminum silicon ratio(A/S)is basically 3.5–5.5, resulting in high ore consumption and alkali consumption in alumina production and lack of competitiveness, has been difficult to support the local large-scale alumina industry. To this end, China's bauxite imports in recent years has shown an increasing trend year by year.

4. Analysis of the technology and cost of alumina industry in China

4.1. Analysis of the technical status of alumina industry in China

China's alumina industry has developed a series of major innovation achievements through decades of independent innovation in view of the resource characteristics of China's medium and low grade diaspore ore. Bayer process indirect heating enhanced dissolution technology and efficient enhanced Bayer process technology solve the key technical problems of using Bayer process to treat diaspore ore [24]; The Bayer process of mineral processing and the Bayer process of lime have solved the technical problems of economic treatment of medium
and low grade diaspore ore to produce alumina [25]. Through digestion, absorption and independent innovation, a series of large-scale energy-saving Bayer process key equipment has been developed, which has realized the large-scale and energy-saving of China's aluminum oxide industry.

4.2. Analysis of the alumina production cost ratio in China

Taking 2019 as an example, the comparison of alumina production and operation cost composition between China and other countries is shown in Figure 3.

![Figure 3: Comparison of alumina production cost distributions in 2019](image)

It can be seen from Figure 3, the biggest difference in alumina production costs between China and other countries is the cost of bauxite. China's bauxite resources are poor and the ore price is high, so bauxite accounts for 41% of the production cost, while foreign countries only account for 24%. However, China's share of other alumina costs is relatively low, mainly because of China's lower labor and maintenance costs.

5. Analysis of the advantages and disadvantages of alumina industry in China.

5.1 Advantages of the alumina production in China

The advantages of China's alumina industry are: huge production capacity, buffer capacity to adjust production, lower prices of domestic mines in the south, a certain degree of competitiveness, lower labor and maintenance costs, coal and caustic soda prices are more reasonable.

It can be seen that China's alumina industry to improve the core competitiveness of the development of ideas lies in: as much as possible to exploit low-cost bauxite, bauxite resources in poor areas of the aluminum oxide plant transfer to the coastal areas to use high-quality imported ore; High efficiency and low consumption alumina production technology has been developed to achieve further energy saving and consumption reduction.

5.2 Disadvantages of the China's alumina industry.

5.2.1 Bauxite resources are in serious shortage.

China's overall bauxite resources lack, low grade, complex composition, difficult to meet the needs of the huge alumina industry, must import bauxite. According to Chinese customs data, in 2023, China imported a total of 141,565,900 tons of bauxite, a record high, an increase of 12.69% over 2022. A total of 99,256,800 tons of Guinean bauxite were imported in 2023, also a record high, an increase of 40.94% over 2022. In 2023, 34,614 tons of Australian bauxite will be imported, an increase of 1.51% over 2022. Guinea and Australia's bauxite imports accounted for 94.56% of the total imports in 2023, occupying an absolute position. In 2023, China's total consumption of bauxite is 216.29 million tons, of which 80.24 million tons of domestic ore consumption, 136.05 million tons of imported ore consumption, imported ore consumption accounts for 62.90% of the total consumption. In addition, according to relevant experts, China's alumina smelting will demand about 220 million tons of bauxite in 2024, see Table 1.

<table>
<thead>
<tr>
<th>Region(Province)</th>
<th>Imported ore</th>
<th>Domestic ore</th>
<th>total demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shandong</td>
<td>7700</td>
<td>0</td>
<td>7700</td>
</tr>
<tr>
<td>Shanxi</td>
<td>1770</td>
<td>3100</td>
<td>4870</td>
</tr>
<tr>
<td>Guangxi</td>
<td>1120</td>
<td>2280</td>
<td>3400</td>
</tr>
<tr>
<td>Henan</td>
<td>950</td>
<td>1290</td>
<td>2240</td>
</tr>
<tr>
<td>Guizhou</td>
<td>0</td>
<td>1200</td>
<td>1200</td>
</tr>
<tr>
<td>Hebei</td>
<td>1300</td>
<td>0</td>
<td>1300</td>
</tr>
<tr>
<td>Chongqing</td>
<td>1020</td>
<td>0</td>
<td>1020</td>
</tr>
<tr>
<td>Yunnan</td>
<td>0</td>
<td>320</td>
<td>320</td>
</tr>
<tr>
<td>Total</td>
<td>13860</td>
<td>8190</td>
<td>22050</td>
</tr>
</tbody>
</table>

It can be said that the resource guarantee problem of imported ore has become the soft underside of China's alumina industry. This has become a problem that China's alumina industry needs to pay great attention.

5.2.2. Alumina industry waste gas purification and standard discharge lack of the advanced technology.

The waste gas of alumina industry mainly includes the flue gas of alumina production, boiler flue gas and other gases containing a variety of pollution sources, among
which the main pollutants are $\text{SO}_2$, $\text{NO}_x$, $\text{CO}$, $\text{CO}_2$, volatile organic compounds, etc., which cause harm to the environment and human body. For alumina industrial waste gas purification and standard emissions, China has no advanced technology, and there is still a certain gap compared with other countries in the world.

5.2.3 There is a lack of reasonable measures for the treatment of alumina industrial pollutants.

The pollutants in the alumina industry are mainly solid waste, of which the solid residue produced by the alumina industry is red mud, because the red mud contains 2 – 5 g/L of attached alkali (in the attached water) and the mass fraction of 3% ~ 12% of the combined alkali (in the solid waste residue), causing pollution to the atmosphere, soil and groundwater. Because of the rapid increase of red mud accumulation in the storage yard and the danger of dam break, it is urgent to solve the problem of safe storage, harmless disposal and large-scale resource utilization of red mud. For the treatment of solid waste such as red mud, China has no corresponding advanced technology and lacks reasonable measures.

6. Strategies and suggestions for the sustainable development of alumina industry in China.

6.1 The disorderly and excessive expansion of alumina smelting capacity should be strictly controlled.

The scale of China's alumina industry is the world's first, the output accounts for more than 50% of the world's total output, the development to the present stage encountered serious resources, energy and environmental constraints, so we must strictly control the total scale of alumina production capacity, the focus of the work shifted to achieve high-quality operation, improve core competitiveness, promote energy conservation and emission reduction and realize resource recycling applications.

We must grasp the direction of capacity transfer. Alumina production capacity should be transferred from bauxite shortage or poor areas to coastal areas suitable for the construction of the aluminum oxide plants or foreign areas rich in bauxite resources, the use of foreign high-quality bauxite production of alumina, in order to reduce alumina production costs, or to energy rich and cheap areas to reduce smelting production costs and improve core competitiveness.

6.2 The poor bauxite resources need to be solved as soon as possible.

To solve the problem of shortage of bauxite resources in China as soon as possible, two approaches need to be taken, one is to speed up the development of efficient utilization technology of domestic complex components of bauxite, the other is to broaden the import channels of foreign high-quality bauxite and efficiently deal with it, or to encourage the construction of factories in the Belt and Road region rich in bauxite resources and energy and politically stable. That is, domestic and foreign resources together.

The domestic complex composition of the monohydrate duralumite mine needs to develop as soon as possible to economically treat the production of alumina technology, need to make a breakthrough in recent years, the focus is on the development of light burning desulfurization technology to treat high-sulfur bauxite, the development of the wet series technology to treat high-silicon bauxite, and try to produce alumina at a lower operating cost than the imported mine.

6.3 The problem of the unreasonable and short energy structure need to be solved.

China's alumina industry needs to make full use of green energy such as abundant hydropower in southwest China, replace thermal power in northern China to produce alumina, and use coal and other resources as little as possible to reduce carbon dioxide emissions.

6.4 The problem of the deep purification and standard discharge of alumina industrial flue gas need to be solved.

The flue gas treatment of China's alumina industry mainly includes dust reduction, desulfurization and removal of the organic matter, which need to implement two methods: clean production and deep purification of emission flue gas. The technology is developed to strictly control the process conditions and reduce emissions in the production process, and for other harmful substances in the flue gas, the corresponding dust reduction and desulfurization technology is used to ensure that the exhaust gas is discharged to the standard.

6.5 The safe storage and resource reuse of the alumina industrial solid waste should be implemented.

It should be vigorously developed safe storage and large-scale low-cost resource utilization technology of red mud. Accelerate the development of technology that can use red mud in large quantities, and produce raw materials and auxiliary additives that can be used in building materials industry, metallurgical industry, chemical industry and environmental industry.

6.6 The deep recovery efficiency of the waste heat utilization in alumina production should be increased.

Considering that in the aluminum oxide production process, the energy consumption of roasting accounts for about 25% to 30% of the comprehensive energy consumption of aluminum oxide, under normal circumstances, the flue gas temperature of the aluminum
hydroxide baking furnace can reach up to 200°C, and the high-temperature baking furnace flue gas will inevitably take away part of the aluminum oxide. At the same time, due to the waste heat of baking furnace flue gas, a lot of heat and water loss, which has a very bad impact on the environment. Partial sensible heat of baking furnace flue gas is used to achieve deep recovery of the residual heat of flue gas. Direct heat exchange between low temperature water and baking furnace flue gas is adopted by spraying method, and the sensible heat of high temperature flue gas is directly transferred to low temperature water, and the latent heat of water steam is also guaranteed to enter the low temperature circulating water. The waste heat of roaster flue gas is used to pre-concentrate the evaporated liquid of the alumina plant, reduce the evaporation water of the evaporation station, thus reducing the evaporation steam consumption, and further achieve the purpose of reducing the energy consumption of alumina production.

7. Conclusion

According to the above analysis, the main challenges facing the development of China's alumina industry include excessive production capacity, unreasonable layout, poor quality of bauxite resources, energy conservation and consumption reduction still lag behind international advanced indicators, serious environmental pollution and lack of key treatment technologies.

In this regard, China's alumina smelting industry should strictly control the disorderly and rapid expansion of production capacity and reasonable layout, optimize the supply structure of resources and energy, implement high quality, energy saving, low consumption to improve core competitiveness, accelerate the realization of exhaust gas, wastewater and solid waste discharge and resource utilization, and realize the stable, healthy and green sustainable development of China's alumina industry.

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