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Twenty Years of Development and Future Prospects of Coal Beneficiation in China

Yang Wang

China Coal Tianjin Design & Engineering Company Limited, Tianjin, 300130, China

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Abstract: In the past 20 years, with the rapid development of China's economy, China's coal preparation technology has made great progress Clean and efficient utilization of coal is the primary task to promote the green and low-carbon transformation of China's energy, and it is also an important technical way for the coal industry to achieve the goal of "double carbon" Coal washing and processing is the premise and foundation of clean and efficient utilization of coal, and it is also the only way for coal industry to transform into clean, low-carbon, safe and efficient direction. Under the influence of "double carbon" policy, coal preparation, as the source and foundation of clean utilization of coal, is facing new challenges and opportunities. This paper reviews the development status of coal preparation technology in China in recent 20 years from the aspects of coal preparation technology, coal preparation equipment and intelligent coal preparation. This paper reviews the problems and solutions in coal preparation industry, and looks forward to the future technology development trend.

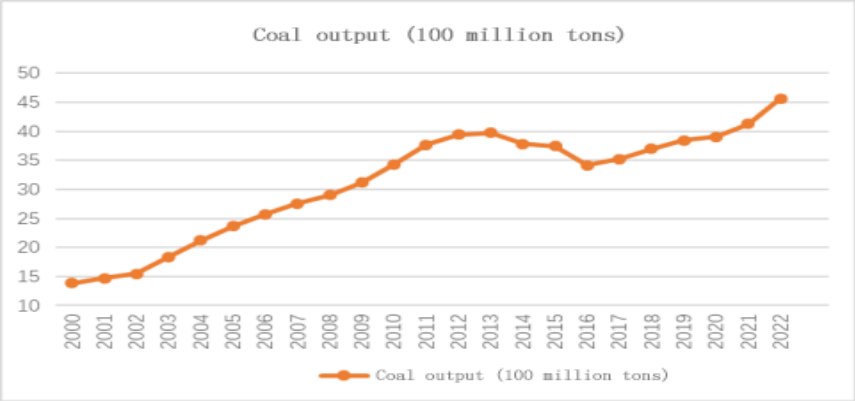
1. Introduction

Clean and efficient utilization of coal is the primary task of promoting the green and low-carbon transformation of China's energy, and it is an important technical way for the coal industry to realize the goal of "double carbon". Coal washing and processing is the premise and foundation of clean and efficient utilization of coal, and it is also the necessary way for the coal industry to transform into clean and low-carbon, safe and efficient. Over the past seventy years since the founding of the People's Republic of China, China's coal washing and processing industry has gone through several changes, gradually developed and expanded, cultivated a large number of excellent researchers, scholars, engineers and technicians, and the production and management level is in the forefront of the world, and the key technology and equipment have reached the world's leading level. However, in terms of key components, tools and means, software control and other aspects, the domestic coal processing technology still has shortcomings. Based on the background of "double carbon", this paper reviews the development of coal processing technology in the past two decades, and combines the current problems of coal washing and processing industry, and looks forward to the future direction of the industry's technology.

2. Twenty years of development

China's oil-poor, gas-poor and coal-rich resource endowment characteristics determine that the status of coal as a major energy mineral will remain unchanged for a long period of time in the future. As an important and indispensable part of the coal industry, coal washing and processing has experienced rapid development in the past two decades.

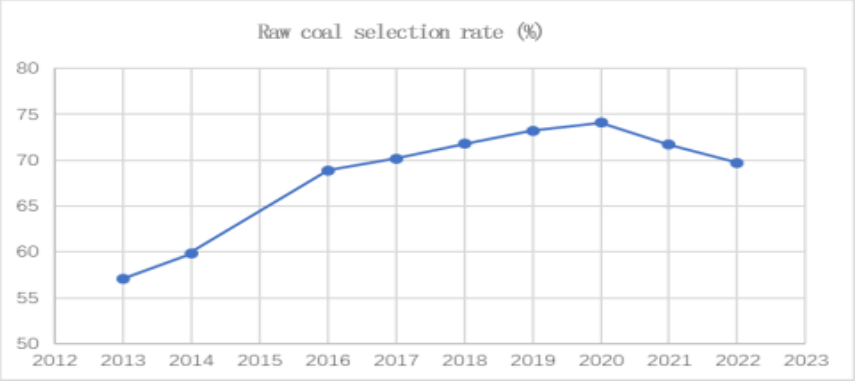
2.1 Industry background



(Data derived from statistical bulletins on national economic and social development over the years)

Figure 1: China's coal production, 2000 to 2022

Coal is an important primary energy source in China, over the past two decades, coal production has gradually increased from 1.384 billion tons in 2000 to 4.56 billion tons in 2022 (as shown in Figure 1), and the coal industry has played a key role in the stable and prosperous development of China's national economy [1]. With the acceleration of industrialization, environmental protection awareness and downstream industry's requirement of coal index, the amount of coal washed has been increasing year by year. Around 2000, China's coal washing rate was only 37%, but in 2022, the rate of raw coal washed has reached 69.70% (as shown in Figure 2). Coal Industry Association in the "14th Five-Year Plan" guidance put forward, in 2025 China's raw coal washing rate is planned to increase to 85%, to realize the selection should be selected as much as possible. It can be seen that the coal washing and processing industry still has a vast space for development.



(Data derived from the annual development reports of the coal industry of the Coal Industry Association for the past years)

Figure 2: China's coal washing rate, 2013 to 2022

2.2 Coal beneficiation process

Over the past twenty years, coal beneficiation methods have become more and more mature, and coal beneficiation process has been perfected day by day, realizing the historic leap from jigging dominance to the coexistence of jigging and heavy intermediary, from the dominance of wet method to the synergistic complementarity of wet and dry methods, and from ungraded mixed coal sorting to the high-precision grading and sorting of narrow particle size. With the efforts of all coal separators, China's coal separation process has successfully ranked among the international advanced ranks, and basically meets the demands for separation and processing of raw coals of different natures [13].

2.2.1 Coking coal beneficiation process

In the past two decades, China has vigorously strengthened the scientific and technological research on coal beneficiation, and developed a large number of high-efficiency coal beneficiation processes suitable for the characteristics of Chinese coals. In the field of coking coal sorting, there are two kinds of typical coal sorting processes in China [14], which are the three-grain sorting process of non-desliming and non-pressurized three-product heavy-duty cyclone sorting + slurry heavy-duty sorting + flotation process and the three-grain sorting process of desliming and three-product heavy-duty cyclone sorting + coarse coal slurry sorting + fine coal slurry flotation process, respectively.

Non-desliming non-pressurized three products heavy media cyclone sorting + coal slurry heavy media sorting + flotation process [2] was firstly proposed by Tangshan Coal Research Institute (now China Coal Technology and Industry Tangshan Research Institute). This process is the first time that domestic controlled heavy media separation technology is applied to the field of coal separation in China, which triggered a boom in the application of heavy media separation technology in large-scale coal preparation plants and created a new situation of heavy media separation in China. Compared with jigging sorting process, this process makes the coal sorting accuracy has been greatly improved, and the sorting system is relatively simple, high degree of automation, especially for coal slurry content of less raw coal sorting. 2000 years later, along with the coal industry "golden decade", coal sorting technology has entered the "heavy media". After 2000, along with the arrival of the "golden decade" of coal industry, coal separation technology has entered into the era of "heavy medium".

Dewatering three products heavy media cyclone sorting + coarse coal slurry sorting + fine coal slurry flotation three-grain sorting process [3] was firstly put forward by Handan Design Institute (now China Coal Tianjin Design Company), the core of this process is to improve the sorting accuracy by narrowing the sorting grain size. The application of this process in Zhangshuanglou Coal Processing Plant shows that this process can achieve better sorting effect on coking coal, and thus it has been vigorously promoted and applied. This process solves the problem of lower washing efficiency caused by the large fluctuation of coal slime quantity in the non-desliming sorting process.

The above two typical processes are the main sorting processes adopted by large-scale coking coal preparation plants in China, but individual small-scale coal preparation plants still adopt the mixed jigging + flotation process due to the consideration of construction capital and operation cost. In addition, in order to maximize the recovery of coking coal, lump coal photoelectric separation, middle coal re-election, multi-section flotation and other technologies have also been developed and applied.

2.2.2 Power Coal Beneficiation Process

The main goal of steam coal washing and processing is to increase the calorific value of coal, so the steam coal preparation plant has low requirements on product quality. The lump coal separation process [4] is widely used in the early steam coal preparation plants to reduce investment and operating costs. The lower limit of particle size of steam coal separation is determined by factors such as coal quality characteristics, product quality requirements and lump coal separation equipment. The lower limit of separation of lump coal dynamic sieve jig is generally 50 mm, the lower limit of separation of lump coal shallow trough heavy medium separator is generally 13 mm, and the lower limit of photoelectric separation of lump coal is generally 50 mm.

In recent years, the requirements of the downstream market on the quality of coal products have gradually increased, forcing the steam coal preparation plant to innovate the production process, and improve the product quality by reducing the lower limit of separation particle size and increasing the amount of raw coal washed. In 2014, Duanwang Coal Preparation Plant used 3mm flip screen to carry out pre concentration dry powder removal process, which is currently the minimum particle size dry powder removal process in China. At present, the lower limit of particle size of pre concentration dry powder removal process is about 6mm.

With the maturity of dry coal preparation technology, the coal preparation process ushers in a new round of reform. The dry separation process has the advantages of no water and no medium, simple process system, low construction investment and production cost, and is especially suitable for the separation of raw coal in cold and water scarce areas or where the coal quality is easy to be slimed [12]. Shanghai Miaoyushujing Coal Preparation Plant is a typical case recognized by the industry. In the existing coal preparation process practice, the dry coal preparation process is widely used in the front row gangue of raw coal preparation. At the same time, the dry process is also applicable to the separation of easy coal or coal with loose product index requirements. The promotion and application of the dry and wet mixed separation process has significantly improved the coal separation efficiency and reduced the construction scale and production cost of the subsequent wet separation system.

2.3 Coal processing equipment

The development and progress of coal preparation technology cannot be separated from the innovation of coal preparation equipment. As the coal preparation production process is a continuous process operation, the reliability of equipment is one of the necessary conditions to ensure the efficient operation of the production system of the coal preparation plant. In addition, with the adjustment of national coal policy, the coal preparation plants in China tend to be large-scale. By 2021, there will be 84 super large coal preparation plants with a raw coal preparation capacity of 10 million t/a or more in China, with a total capacity of more than 1.3 billion t/a and an average capacity of 15 million t/a [11]. For a long time, the large-scale exploration and reliability research of coal preparation equipment have been the focus of coal preparation workers [5].

2.3.1 Crushing equipment

The most commonly used crusher in the coal preparation plant is the double toothed roll crusher. Although the domestic classification crushing technology started late, it has developed rapidly. In particular, during the "11th Five Year Plan" and the "12th Five Year Plan", large-scale domestic classification crushers have been developed by leaps and bounds, and the gap between related products and advanced equipment such as British MMD, South Africa SHEAR, Australia ABON

has been significantly narrowed. From the perspective of single machine processing capacity, installed power, upper limit of feed particle size and other indicators, domestic equipment basically meets the requirements of production systems of various large coal preparation plants, Localization substitution [9] has been realized.

2.3.2 Screening equipment

In the past decade, private enterprises among screening machinery manufacturers in China have developed rapidly. At present, screening equipment manufacturing industry cluster centers have been formed in Tangshan, Anshan, Xinxiang, Tianjin and other places. On the basis of absorbing domestic and foreign technologies and drawing on the relevant technologies of the industry, domestic R&D personnel continue to make independent innovation. Some equipment has reached or approached the world's leading level. Banana screens with a length of about 9.5 m and a width of about 7.0 m, high-frequency vibrating screens with a span of 2.4 m, box linear vibrating screens with a span of 4.3 m Screening equipment such as round vibrating screen with a span of 3.6 m and elliptical vibrating screen with a span of 5.05 m. In addition, in the field of dry screening, cross screens and flip screens are emerging, especially the Liwell flip screen [10].

2.3.3 Washing equipment

(1) Jigger

In the past 20 years, the research progress of domestic jigs has gone through several stages. The movable sieve jigger is mainly used for selecting front gangue. Fixed sieve jigs mainly include LTX, X, SKT, etc. SKT series jigs have a glorious history of development and are still the first choice for jigging coal preparation plants.

(2) Heavy media shallow tank sorters

Heavy medium coal preparation in China began in 1956, and a series of products such as inclined wheel heavy medium separator, vertical wheel heavy medium separator, shallow trough heavy medium separator have been successfully developed. Among them, the shallow through dense medium separator is widely used, which is widely used in large domestic coal preparation plants. The maximum processing capacity of single equipment can reach 800t/h.

(3) three-product heavy-duty cyclones

In the late 1990s, China Coal Technology Industry Tangshan Research Institute successfully developed a large-scale three-product heavy media cyclone and its supporting technology without pressure feeding and mud separation, and since then, China Coal Technology Industry Tangshan Research Institute, Guohua Science and Technology Company, Weihai Haiwang Company successively launched a series of three-product heavy media cyclone. In recent years, the development of three products of heavy media cyclone mainly focuses on the density of accurate online control and energy saving. For example, China Coal Tianjin Design Company has developed a series of high-precision three-product heavy-duty cyclone products [7], realizing the online adjustability of the density of the second cyclone sorting.

(4) Flotation equipment

The development of coal flotation equipment in recent years is towards large-scale, integrated and intelligent rapid development. Many kinds of advanced large-scale flotation equipment have been developed in China. The maximum single cell volume of mechanical agitation flotation machine has reached 90m ^{3}, and the maximum diameter of flotation column has reached 5.5m. In addition, in order to solve the problem of low rank coal flotation that has been widely concerned in recent years, researchers have carried out a series of technical breakthroughs on the jet microbubble flotation machine, and have developed a jet microbubble flotation machine [8] with a maximum

diameter of 6.5m.

2.3.4 Coal slurry water treatment equipment

In terms of centrifugal dewatering equipment, the common centrifugal dewatering machines in the coal preparation plant include vibrating discharge centrifuge, scraper discharge centrifuge and sedimentation filtering centrifuge. The horizontal vibrating centrifuge is the focus of current research. At present, the maximum diameter of the horizontal vibrating centrifuge has reached 1.6m, and the processing capacity can reach 300t/h.

In terms of concentration equipment, the main domestic applications are rake thickeners, inclined tube thickeners, deep cone thickeners and high-efficiency thickeners, of which the rake thickener is the most widely used, and the diameter of the largest rake thickener at present can reach 100 m.

In terms of filter press, ultra-high pressure filter pressing and dewatering technology for fine slime is a new filter pressing technology developed in recent years. With ultra-high water pressure pressing, cross flow air pressing and other methods, the maximum press pressure of the filter press can reach 10MPa, and the dewatering filter cake can reduce 8%~10% of the water content and increase the heat output by 500~600kcal/kg.

2.3.5 Other new equipment

In the large-scale, localization at the same time, new coal processing equipment is also emerging. Three products represented by the Kingstone Technology Company products interference bed sorting machine, Tangshan Shenzhou Machinery Group represented by the composite dry sorting equipment, Shijiazhuang Gongbe company products represented by the cross, Anhui Fangyuan company represented by the multi-layer stacked sieve, Tianjin Meiteng company products represented by the horizontal photoelectric dry selector, Ganzhou good friend company products represented by the vertical photoelectric dry sorting machine, and so on.

2.4 Intelligent coal processing

In recent years, the wave of intelligence has swept into the field of coal washing and processing, and all ministries and commissions have put forward clear requirements. China's coal plant has invested a lot of manpower and material resources, and actively promote the intelligent construction of coal plant, coal plant production by mechanization, automation, information technology and gradually transformed to intelligent.

With the deepening of intelligent construction of coal preparation plant, large coal industry groups will build a three-dimensional hierarchical intelligent operation and maintenance service system: the plant level coal preparation plant will set up an edge data center, equipped with "nurse level" intelligent talents, and carry out end management and control; The region has a data center, equipped with "doctor level" intelligent talents, serving small regions; The Group has set up a data center based on business characteristics, equipped with "expert level" intelligent talents to provide strategic guidance and high-end intelligent services. The traditional operation and maintenance mode is unsustainable, the system and mechanism are constantly innovating, and the production management and control mode is ushering in reform, which may lead to professional online reservation maintenance companies, equipment supermarkets in the washing industry, remote industrial IT operations and other emerging products [6].

3. Future prospects

In the past two decades, the development of coal selecting technology in China has made remarkable achievements, but there are still some problems, which is also the direction of our future efforts. The

(1) The proportion of raw coal inductions needs to be improved

Influenced by many factors, in the past three years, China's coal production has increased year by year, but the coal washing rate has not increased with the increase of coal production, which indicates that the development of coal washing industry has a big lag. This shows that there is a big lag in the development of coal processing industry. 2022, China's raw coal washing rate is less than 70%, which is still a big gap from 85% pointed out in the "14th Five-Year Plan". Therefore, improving the washing rate of raw coal is one of the priorities of coal processing in the middle and late 14th Five-Year Plan.

(2) Key equipment and directed research and development urgently need a breakthrough

The national policy is gradually guiding the coal processing plant to large-scale development, and with the application and promotion of new coal processing technology. In order to ensure the green and energy-saving development of coal beneficiation industry, coal beneficiation plants are in urgent need of large-scale high-efficiency classifying and sorting equipment with annual processing capacity of 10 million tons and above for single system and single set. In the future development, coal processing workers urgently need to break through the technical barriers of key large-scale washing equipment, and strive to improve the localization rate of coal processing plant equipment [15].

(3) Intelligent construction bottlenecks remain unresolved

Since 2020, the Development and Reform Commission, the Energy Bureau and other relevant parties have launched a series of coal mine intelligence-related policies and standards, greatly promoting the high-quality development of the coal industry. However, on the whole, the coal plant intelligent sorting link still exists "their own way" problem, intelligent coal plant lacks a mature and unified decision-making and collaborative control system for the whole process.

(4) The clean and efficient utilization of low-rank coal still needs efforts

Inner Mongolia and other regions there is a considerable amount of low-rank coal, with the depletion of coal resources in North China, East China and other regions, the clean and efficient utilization of low-rank coal in the northwest region will become the focus of the coal industry in the future.

(5) Difficulties in the treatment of solid waste from coal beneficiation

Coal slurry, gangue and other solid wastes in the process of coal beneficiation have a greater impact on the environment, and the treatment of such solid wastes often requires enterprises to pay high treatment fees [16]. Academics around the coal-based solid waste treatment technology has carried out a lot of research, the birth of the overburden off-seam slurry filling, gangue soil reclamation technology, but from the perspective of the cost and the universality of the technology, this kind of technology is still awaiting in-depth research and popularization.

4. Conclusion

The coal industry is the key to realizing the goal of "double carbon" in China. With the advancement of carbon neutrality, China's energy consumption pattern will undergo a fundamental transformation, and coal will gradually evolve from a basic energy source to a guaranteed energy source. The "dual-carbon" strategy accelerates the transformation of coal into both fuel and raw material, which has given rise to higher requirements for coal processing technology, and ushered in the development opportunity of transformation and upgrading for the coal processing industry.

Looking back to the past and looking forward to the future, China's coal processing industry has made great progress. Under the background of "double carbon", coal processing industry should actively seek for energy efficient washing methods and measures, energy saving and consumption reduction, and constantly improve the level of coal clean conversion and utilization, so as to realize the clean and efficient utilization of coal, and help the country's economy continue to develop in a good way. This is the first time that we have seen the development of coal washing industry in China.

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