Present and future of coal use in China

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Abstract. In recent years, global warming has gradually intensified, and after the signing of the Paris Agreement, countries have gradually established emission targets of "carbon peak" and "carbon neutrality". This paper mainly discusses the main application areas and problems of coal under China's plans to achieve the dual carbon goals in 2035 and 2050 respectively, as well as the challenges China will face in clean coal use in the future. This paper argues that clean energy is an international trend, and countries around the world need to plan energy according to their respective resource endowments. China is in the midst of a transition period from high carbon to low carbon and no carbon. As a matter of current trends, China's total energy demand will still increase, but it is not yet ready to achieve a full replacement of coal from renewable energy. Therefore, in the coming decades, the development of clean coal is an important part of China's sustainable development path. Among China's proven fossil energy reserves, coal accounts for about 94%, which is the energy source with the strongest ability to stabilize the economy and guarantee itself. Deeply understanding China's energy resource endowment and the basic guarantee role of coal, and doing a good job in the clean, efficient and sustainable development and utilization of coal is a choice that conforms to the current basic national conditions and basic energy conditions.

Keywords: Coal use, China, current situation, prospects.

1. Introduction

In the context of global warming and vigorous promotion of green and low-carbon development, China proposed the goal of carbon peak and carbon neutrality and discussed the present and future of China's coal use. Since the 21st century, global greenhouse warming has gradually intensified. As the largest developing country, China has long been at the forefront of carbon emissions in the world. In order to reduce the impact of high carbon emissions on the environment, China has set the "dual carbon" goals, requiring carbon peaking by 2035 and carbon neutrality by 2060. The use of coal is the main source of carbon dioxide production in China. In order to achieve the dual carbon goal, how to optimize the use of coal is a question worth considering in today's society.

First, this article briefly introduces the classification of coal in use. Then, the role of coal in the four main application modes of thermal power generation, steelmaking, chemical industry and building materials and the status quo of the four main application fields of coal were discussed. Secondly, the environmental impact of coal in various applications is introduced, including the discharge of flue gas, wastewater, waste residue and dust. It also describes some of the environmental challenges facing the development of coal use in China. Finally, several lists of policy and technical future directions for cleaner coal use are listed.

2. Classification of Coal in Use

Coal is mainly divided into two types: thermal coal and coking coal in use.

2.1. Definition of Thermal Coal

Thermal coal is a type of coal that serves as both a power raw material and fuel for various applications. It possesses specific qualities that make it suitable for coal combustion and heating, making it an essential resource for activities such as power generation, building materials manufacturing, and even coal chemical industry processes. It is a versatile fuel that can be utilized in multiple ways. The term "thermal coal" can be understood in two distinct senses. In the narrow sense, it specifically refers to coal utilized for thermal power generation. This constitutes the primary and most commonly recognized meaning of thermal coal. However, in the broad sense, thermal coal encompasses a broader range of applications. It includes all types of coal utilized for power generation, locomotive propulsion, and boiler combustion, serving as a source of energy across various sectors. National standards provide a framework for categorizing thermal coal into specific types. These categories include lignite, long-flame coal, non-stick coal, lean coal, gas coal, and to a lesser extent, anthracite. Each category exhibits different attributes and properties that determine its suitability for different applications.

2.2. Definition of Coking Coal

Coking coal is a specific type of coal that comes from bituminous coal and includes different types of coal such as lean coal, lean coal, coking coal, fat coal, 1/3 coking coal, gas fat coal, gas coal, and 1/2 sticky coal. The main use of coking coal is for the production of coke, which plays an important role in multiple industrial fields.

According to different usage purposes and industrial needs, coking coal can be further divided into different categories. The following are the main categories of coking coal:

(i) Metallurgical coke: Metallurgical coke is a major application form of coking coal, widely used in the ironmaking process in the metallurgical field. Metallurgical coke includes blast furnace coke, cast coke, and ferroalloy coke. These coking coal undergo a process of reduction and melting under high temperature conditions, providing fuel and reducing agent functions to promote the reduction and melting process of iron ore.

(ii) Gasified coke: Gasified coke is another important application form of coking coal, used in the coal gasification process. In the process of coal gasification, coking coal undergoes high-temperature and high-pressure gasification reactions to produce synthetic gases, including carbon monoxide and hydrogen gas. This synthetic gas can be used for the production of synthetic chemicals, fuels, and energy.

(iii) Calcium carbide coke: Calcium carbide coke refers to coking coal used for the production of calcium carbide. Calcium carbide is a chemical substance produced by electrolysis of limestone and charcoal, used in the manufacture of chlor alkali chemical products and other chemicals.

Overall, coking coal refers to a specific type of coal used for the production of coke. Different types of coking coal play an important role in various industrial fields, meeting the needs of industries such as metallurgy, coal gasification, and calcium carbide.

3. Coal for Thermal Power

3.1. Composition and Equipment of Thermal Power Plants

Thermal power plants typically consist of fuel system, combustion system, steam water system, electrical system control system, auxiliary equipment. The fuel system is used to supply fuel to thermal power plants. This includes different types of fuels such as coal, natural gas, oil, and biomass. After being processed and stored, the fuel is transported to the boiler for combustion. The combustion system mainly consists of a boiler, which is used to burn fuel to produce high-temperature and high-pressure combustion gases. The heat energy released by the combustion process in the boiler is used to generate steam. The steam water system includes equipment for generating and transporting steam. In a boiler, the thermal energy generated by combustion is converted into steam, which generates power in the steam turbine. The steam water system also includes a water supply circulation system for circulating cooling and re converting into steam. The electrical system control system is used to monitor and control the operation of various equipment in thermal power plants. It includes control and protection systems for generators, transmission systems, switchgear, instrumentation, and automation systems. In addition to the main equipment such as boilers, steam turbines, and generators, thermal power plants also include a series of auxiliary equipment. These equipment include a water supply system to provide makeup water for the boiler; Water supply equipment for firefighting and other water needs; Water treatment equipment, used to treat circulating water and wastewater in the factory; Dust removal equipment, used to control and reduce the emission of solid particles in flue gas; Fuel storage and transportation equipment, used to store and transport fuel to boilers.

In addition, the main transformer and distribution device are generally placed in independent buildings or outdoors, responsible for boosting the electrical energy generated by the generator and transmitting it to the power grid. The effective operation and coordination of these equipment are key to ensuring the safe and efficient operation of thermal power plants.

3.2. Principle of Thermal Power Generation

In a thermal power plant, fuel is burned in the boiler, which releases heat. The heat generated is transmitted to the water within the boiler, resulting in the production of high temperature and high-pressure steam. The high-pressure steam is then directed to a steam turbine, where it undergoes expansion, and the kinetic energy of the steam is converted into rotating power. The rotating power from the steam turbine drives a generator, which converts the mechanical energy into electrical energy. This electrical energy is then transmitted to the power grid for distribution to consumers.

3.3. Current Situation of Thermal Power Generation

Thermal power generation indeed plays a crucial role in the development of electricity in modern society. It is one of the primary methods used to generate electricity on a large scale, providing a significant portion of the global electricity supply. The reliable and consistent power output of thermal power plants helps meet the increasing demand for electricity, supporting industrial, commercial, and residential activities. We move towards a more sustainable future, it is important to focus on improving thermal power technology in ways that minimize its impact on the environment and reduce our dependence on non-renewable energy sources. This can be achieved through various measures such as increasing the efficiency of thermal power plants, reducing greenhouse gas emissions, implementing advanced pollution control technologies, and promoting the use of cleaner fuels. While the presence of nuclear power units in China contributes to the overall electricity generation mix, thermal power plants, particularly those fueled by coal, still dominate the electricity market. This is primarily due to the abundant coal reserves in China and the historical reliance on coal as a source of energy. However, China has been actively working on diversifying its energy sources and promoting renewable energy technologies to reduce its dependence on thermal power and address environmental concerns. The circular economy concept, which aims to maximize resource efficiency and minimize waste generation, is gaining importance in the energy sector. It encourages the reutilization of waste heat from thermal power plants, making the overall system more efficient and sustainable. By integrating such concepts into the design and operation of thermal power plants, we can move closer to a harmonious society where economic development and environmental protection go hand in hand.

4. Coal for Steel

4.1. Role of Coal in Steelmaking

Coal is the main energy source for steel production, and the coal used is mainly coking coal, anthracite coal and thermal coal, and it is converted into different energy forms according to the energy needs of different processes. About 85% of the coking coal is converted into coke (powder) for use in the blast furnace during the coking process, and the rest of the energy is released in the form of heat energy; Anthracite has a high degree of coalification, strong firepower, and the combustion intensity is comparable to coking coal, coke or coke powder, but the price is cheaper, so it is used as fuel in the sintering process and as injection coal in the blast furnace process, which plays an important role in improving the level of steel technology and economic benefits; Thermal coal is mainly processed and converted into electricity and steam for use by steel enterprises in production operations and logistics support, and the proportion of direct combustion is very low. It can be seen that the role of coking coal (carbon) in the coking and blast furnace process, anthracite in the sintering and blast furnace process is specific and irreplaceable, and the role in production guarantee can actually be replaced by thermal coal.

4.2. Current Situation of Coke Steelmaking

China's coke supply is sufficient, the output is relatively stable, 2015-2021 remained between 4-500 million tons, the steel industry in the first half of 2022 continued to be sluggish, coke enterprises' profit space was significantly compressed, production enthusiasm was low, output increased by only 0.5% over the previous period, to 240 million tons; at the same time, the conflict between Russia and Ukraine led to more tight global energy supply, price fluctuations, and imported coke prices also rose sharply, forming a "inverted" phenomenon of domestic and foreign coke prices. In the first half of 2022, China imported only 246,000 tons of coke, a decrease of 71.5% over the same period of the previous year. The export scale increased by 20.7% year-on-year to 4.127 million tons.

5. Chemical Coal

5.1. Definition of Coal Chemical Industry

The coal chemical industry plays a significant role in converting coal into various forms, including gases, liquid fuels, solid fuels, and chemicals through chemical processing techniques. This industry utilizes coal as the primary raw material for these processes. The coal chemical industry encompasses several processes, including coal gasification, liquefaction, dry distillation, tar processing, and the production of calcium carbide and acetylene chemicals. Coal gasification involves reacting coal with a gasifying agent, such as steam or oxygen, to produce a synthesis gas (syngas) containing carbon monoxide, hydrogen, and other gases. Liquefaction is the process of converting coal into liquid fuels, such as synthetic crude oil or refined petroleum products. Dry distillation is a method used to heat coal in the absence of air, leading to the release of volatile components such as gases and tars. Tar processing involves separating and refining the tarry components derived from coal for various applications. Coal is composed of organic matter, which consists of complex macromolecular structures. These structures are based on aromatic thick rings, with bridge bonds connecting them. These unique molecular arrangements contribute to the diverse properties and reactivity of coal. Thermal and catalytic processing techniques are used to convert coal into different types of fuels and chemical products in the coal chemical industry. Through thermal processing, coal can be transformed into gases, liquid fuels, and solid fuels. Catalytic processing utilizes catalysts to facilitate chemical reactions and produce specific products. The industry produces a wide range of fuels for energy generation and chemical products for various industries, contributing to the economy and meeting demand in different sectors.

5.2. Coal Chemical Industry Development Field

After years of development, the layout of China's coal chemical industry chain has gradually improved, and it has gradually extended from the original traditional coal chemical industry to the new coal chemical industry, and with the development of China's coal chemical industry, it has also carried out business expansion. Starting from the early coal coking business, gradually extending to coal gasification and other fields with methanol as the production node, at this stage, a dual-line business pattern including traditional coal chemical industry and new coal chemical industry has been formed, starting from coal raw materials, a comprehensive business platform of "one head, two lines and multiple production" has been established.

5.3. Coal Chemical Industry Chain

The coal chemical industry can be classified into two sectors: the traditional coal chemical industry and the modern coal chemical industry. The traditional coal chemical industry primarily focuses on the coking industry chain, which includes processes and products related to coal-to-coke, calcium carbide, and synthetic ammonia. China is the global leader in the production of these products. Coal-to-coke involves the conversion of coal into coke, a crucial raw material for steelmaking. Calcium carbide is produced by reacting coal with calcium oxide and is used in various applications, including acetylene production. Synthetic ammonia is a key chemical compound used in fertilizers and other industries. The modern coal chemical industry aims to achieve comprehensive and efficient utilization of coal resources. It focuses on producing clean energy and chemical products through advanced technologies. Some examples of modern coal chemical processes include coal-to-olefin/aromatics, coal-to-natural gas, coal-to-ethylene glycol, and coal-to-liquid. These processes involve converting coal into valuable products such as polymers, natural gas substitutes, ethylene glycol (used in the production of plastics and antifreeze), and liquid fuels. The development of the modern coal chemical industry is crucial for China's petrochemical substitution strategy, which aims to reduce reliance on imported petroleum products. By utilizing coal resources more efficiently and producing clean energy and chemical products, China can reduce its dependence on fossil fuels while promoting domestic energy security. The development and expansion of the modern coal chemical industry also drive structural adjustments within the coal industry. It allows for the transformation of coal resources into higher-value products and promotes cleaner and more efficient utilization of coal. This shift helps to address environmental concerns and support sustainable development in the coal industry and related sectors.

5.4. Coal Chemical Process

The coal chemical production process has the ability to save carbon, and the development of coal chemical industry meets the requirements of "dual carbon". Coal as a raw material to participate in the chemical reaction, part of the carbon into the product, converted into clean energy or chemicals, part of the carbon element into carbon dioxide, a small amount of carbon element with ash loss, because part of the carbon into the product, and coal fully burned carbon all converted into carbon dioxide, so the coal chemical production process has the ability to save carbon. Traditional coal chemical industry, that is, coal coking-related products, include coal-to-synthetic ammonia (fertilizer, building materials), coal-to-coke (ironmaking and non-ferrous metals), coal-to-calcium carbide (PVC plastic products). At present, the main development of coal-to-liquid, coal-to-natural gas, coal-to-olefin, coal-to-ethylene glycol and other four major industries, mainly producing oil and gas and related products (olefins, alcohols, oil, acids, ethers, etc.), is the main route for China to achieve petrochemical substitution.

6. Coal for Building Materials

6.1. Main Way to Use Coal for Building Materials

Mainly for coal fired cement, the production process can usually be summarized as "two grinding and one burning", which can be divided into four steps: 1. Raw meal preparation: that is, calcareous raw materials, clay raw materials and a small amount of corrected raw materials are crushed according to a certain proportion of cooperation, grinding and blending into raw materials with suitable composition and uniform quantity and quality. 2. Preparation of pulverized coal: The coal required for the calcination of cement raw meal must be prepared into pulverized coal to provide the particle size required for pulverized coal combustion, so as to facilitate full combustion and obtain sufficient combustion reaction capacity.

6.2. Current Situation of Coal-fired Cement

Since the reform and opening up, China's cement industry has made great development. The achievements are remarkable, first of all, in the rapid growth of production. In 1980, China's cement output was more than 80 million tons, and now the annual output is close to 500 million tons, ranking first in the world, with an annual output of about 1/3 of the world's annual output, and the output in 1997 is about 6 times that of 1980, which is higher than the development rate of China's GDP. In

2003, the annual output of cement reached 860 million tons, accounting for about 40% of the world's total output, ranking first in the world. Therefore, it strongly supports the rapid development of China's economy and meets the needs of large-scale infrastructure construction and construction project development. Modern cement production heat consumption is less than 3000kJ/kg clinker. The average coal consumption of China's key large and medium-sized cement plants is 175kg of standard coal / ton of clinker, 50% higher than the international advanced level, China's annual output of 500 million tons of cement, of which clinker accounts for about 70%, that is, 350 million tons, coal consumption is about 84 million tons of standard coal, accounting for about 6% of the country's total energy consumption.

7. Environmental Impact of Coal Use

7.1. Emission of Flue Gas

CO_2 is a primary product emitted from coal burning. Excessive burning of fossil fuels, including coal, and deforestation have led to a significant increase in atmospheric CO_2 concentrations. This increase contributes to the greenhouse effect, trapping heat in the atmosphere, and resulting in abnormal rises in global temperatures. CO_2 is now recognized as a greenhouse gas that contributes to climate change. Elevated levels of CO_2 in the atmosphere contribute to the warming of the planet, which can have adverse environmental consequences. Incomplete combustion of carbon during coal burning can produce carbon monoxide (CO), which is a lethal gas when inhaled in high concentrations. CO can be harmful to both human health and the environment. Coal burning and other industrial processes also produce sulfur oxides (SO_x). SO_x emissions contribute to air pollution and can cause various health issues in humans, including bronchitis, asthma, pulmonary heart disease, and other respiratory problems. SO_x can also lead to reduced crop yields and the wilting of vegetation. The burning of fossil fuels, such as coal, releases nitrogen oxides (NO_x) into the atmosphere. Nitrogen oxides also contribute to the formation of acid rain when they react with other pollutants in the atmosphere. Acid rain can have detrimental effects on ecosystems, damaging forests, bodies of water, and infrastructure. In conclusion, the burning of coal and the associated release of CO_2, SO_x, and nitrogen oxides have significant environmental and health implications. It contributes to climate change, air pollution, respiratory diseases, ozone depletion, and acid rain. Transitioning to cleaner energy sources and adopting sustainable practices are essential to mitigate these adverse effects and protect human health and the environment [1].

7.2. Dust Generation

Productive dust refers to solid particles that are generated during production processes and remain suspended in the air of the workplace for an extended period of time. The size of dust particles plays a crucial role in their behavior in the air. Smaller particles tend to be more stable and can remain suspended for longer periods, increasing the likelihood of inhalation. When workers inhale productive dust, it can pose health risks. The dust particles can settle on the walls of the bronchial and alveolar tubes in the respiratory system, potentially causing respiratory issues and other health problems. Prolonged and repeated inhalation of productive dust can lead to the development of systemic diseases, particularly those characterized by pulmonary tissue fibrosis. One such disease is pneumoconiosis, which is recognized as an occupational disease. Different types of pneumoconiosis exist, including silicosis, coal pneumoconiosis, welder pneumoconiosis, asbestosis, and cement pneumoconiosis. These diseases involve the proliferation of collagen fibers in the lungs, leading to fibrosis and impaired lung function. Silicosis is a specific type of pneumoconiosis that occurs due to prolonged exposure to high concentrations of free silicon dioxide (SiO_2) dust, commonly known as silicon dust. Silicosis is typically associated with occupations involving activities like mining, construction, and sandblasting. Inhalation of silicon dust with a content exceeding 10% can lead to the development of silicosis [2].

7.3. Discharge of Wastewater

Wastewater from thermal power plants may contain acidic or alkaline substances. These substances will cause changes in the pH value of the water body, gradually acidification or alkalization, thereby reducing the self purification ability of the water body. Wastewater from thermal power plants may contain oil and grease, which may be caused by oil and grease leakage from mechanical equipment, lubricants, or other industrial processes in the plant. The presence of oil can cause the formation of floating oil on the surface of water bodies, affecting gas exchange and the survival of aquatic organisms. Thermal power plant wastewater may contain suspended solids, mainly dust, solid waste, and coal ash. These suspended solids will increase the turbidity of the water body, reduce the transparency of the water body, and have an impact on the photosynthesis of underwater plants and the living environment of aquatic organisms. Wastewater from thermal power plants may contain organic pollutants, such as chemical residues and organic matter generated from coal combustion. The presence of organic matter can lead to the depletion of oxygen in water bodies, thereby affecting the survival and reproduction of aquatic organisms. Thermal power plant wastewater may contain rich nutrients such as nitrogen, phosphorus, etc. After these eutrophic substances enter the water body, they will promote the excessive growth of algae and aquatic plants, form eutrophication problems such as red tides, disrupt the ecological balance of water, and pose a threat to the living environment of aquatic organisms. Thermal power plant wastewater may also contain trace elements, such as heavy metals. The excessive concentration of these trace elements may have toxic effects on aquatic organisms and pose a threat to the health of aquatic ecosystems. summary, the wastewater discharged from thermal power plants contains various components that have varying impacts on the water ecosystem. Therefore, it is necessary to treat and monitor the wastewater from thermal power plants in a reasonable manner to reduce its harm to the environment [3].

7.4. Output of Waste Residue

Waste residue from coal combustion refers to the byproducts left behind after burning coal. It primarily includes fly ash and slag. Fly ash is a fine, powdery material that is carried away by flue gases during coal combustion. It is typically collected by dust collectors or electrostatic precipitators in power plants. Slag is a course, dense material that settles at the bottom of the boiler combustion chamber. It is removed from the chamber and transported to an ash field through a pressure ash removal pipeline. The boiler combustion chamber is the part of a power plant where coal is burned to produce heat. Slag is formed and accumulates in this chamber. This is a system used to transport slag from the boiler combustion chamber to an ash field. It helps in efficient disposal of slag. Silica is a common component of coal ash slag. It is a mineral compound made up of silicon and oxygen. Farmland can be negatively affected by the accumulation of coal ash residues. The presence of these residues can degrade soil quality and impact crop productivity. Secondary pollution occurs when coal ash residues, including trace elements and toxic substances, are released into the environment and contaminate air, water, or soil. This can have adverse effects on ecosystems and human health. Some coal ash may contain radioactive elements. When released into the environment, these elements can pose radiation hazards and long-term health risks. The presence of certain trace elements and radioactive elements in coal ash can potentially increase the risk of cancer in exposed populations, making it a significant health concern. In summary, waste residue from coal combustion, including fly ash and slag, contains various elements and compounds that can pose environmental and health risks. Proper management and disposal of these residues are crucial to mitigate the potential adverse effects on ecosystems and human health [4].

8. Environmental Challenges to China's Coal Use

8.1. Purification Technology during Combustion

Clean coal technology refers to a set of practices and technologies that aim to reduce pollution emissions and improve utilization efficiency in the development and utilization of coal. One of the key aspects of clean coal technology is the implementation of combustion purification technology, which includes various techniques and processes focused on enhancing efficiency and reducing pollution emissions during coal combustion in power plants.

Advanced burner technology plays a crucial role in clean coal technology. Low-NO_x burners are an example of advanced burner technology that helps in reducing polluting emissions and improving boiler efficiency. These burners achieve this by carefully controlling the fuel and air mixing process, adjusting the mixing ratio to optimize combustion, and lowering the flame temperature. By carefully managing these factors, the production of nitrogen dioxide (NO_2), which is a harmful pollutant, is significantly reduced.

In addition to advanced burners, there are other technologies employed in clean coal technology to further reduce pollution emissions. For instance, limestone multi-stage burners are used for furnace desulfurization. This process involves injecting limestone into the furnace, which reacts with sulfur dioxide (SO_2) produced during combustion to form calcium sulfate ($CaSO_4$), a solid waste that can be easily removed. This helps in reducing sulfur emissions, which are a major contributor to air pollution.

Natural gas reburners are another technology used in clean coal technology. Natural gas reburners involve injecting natural gas into the combustion chamber after the initial coal combustion. This process helps in reducing nitrogen oxide (NO_x) emissions by introducing a fuel source that produces lower levels of NO_x compared to coal.

Furnace desulfurization is another important technique employed in clean coal technology. It involves various methods to remove sulfur-containing compounds from the flue gas generated during coal combustion. By removing these sulfur compounds, the emissions of sulfur dioxide (SO_2) are reduced, thereby minimizing the environmental impact.

Overall, clean coal technology encompasses a range of technologies and processes aimed at reducing pollution emissions and increasing the efficiency of coal-fired power plants. Through the application of combustion purification technology, such as advanced burners, limestone multi-stage burners, natural gas reburners, and furnace desulfurization, significant improvements can be achieved in terms of reducing air pollutants and optimizing the utilization of coal resources [5].

8.2. Solve the Problem of Sulfur Dioxide Emission Pollution

Sulfur dioxide pollution is a significant environmental issue in China, and it has resulted in a considerable portion of the country experiencing low pH levels in average annual precipitation, commonly known as acid rain. The Chinese government recognizes the seriousness of this problem and has made substantial efforts to control sulfur dioxide pollution.

One approach to tackling sulfur dioxide pollution is through source treatment. This involves implementing measures to address the root causes of pollution. One method is the use of low-sulfur coal, which has a lower sulfur content compared to high-sulfur coal. By promoting the use of low-sulfur coal, the emissions of sulfur dioxide can be significantly reduced. Additionally, strict control measures are implemented to regulate the usage of high-sulfur coal, further mitigating sulfur dioxide emissions.

Coal washing is another source treatment technique employed in China. It involves the removal of impurities, including sulfur-containing compounds, from coal before it is combusted. By washing coal, the sulfur content can be reduced, resulting in lower sulfur dioxide emissions during combustion.

Flue gas desulfurization is an effective end-of-line treatment used to remove sulfur dioxide from the flue gas generated during combustion. China has implemented the limestone-gypsum method, which is a mature technology for flue gas desulfurization, in some power plants. In this process, the flue gas is passed through a scrubber where it comes into contact with limestone slurry. The sulfur dioxide reacts with the limestone to form calcium sulfite, which is further oxidized to produce gypsum. This method has proven to be effective in reducing sulfur dioxide emissions in power plants.

However, both source treatment and end-of-line treatment methods can be costly to implement, especially in large-scale applications. As a result, there is ongoing exploration of high-tech desulfurization technologies for power plants. These technologies aim to develop more efficient and advanced methods to remove sulfur dioxide from flue gas, potentially offering more cost-effective and environmentally friendly solutions.

In conclusion, sulfur dioxide pollution is a significant concern in China, leading to low pH levels in average annual precipitation. The Chinese government has taken measures to address this issue through source treatment, including the use of low-sulfur coal, strict control over high-sulfur coal usage, and coal washing. Flue gas desulfurization, employing mature technologies like the limestone-gypsum method, is utilized in some power plants as an effective end-of-line treatment. However, the high costs associated with these treatments have prompted the exploration of high-tech desulfurization technologies for power plants to achieve more efficient and economical solutions [6].

8.3. Low NO_x Pulverized Coal Combustion Technology

During the coal combustion process, nitrogen oxides (NO_x) are generated in two main forms: high-temperature NO_x and fuel-type NO_x.

High-temperature NOx is formed through the oxidation of nitrogen in the air at temperatures higher than 1500°C. This process occurs primarily in the combustion zone where the temperature is the highest. However, in the case of solid slag pulverized coal furnaces, the furnace temperature is typically lower than 1500 °C. As a result, the contribution of high-temperature NO_x from pulverized coal combustion is relatively smaller in these types of furnaces.

On the other hand, fuel-type NO_x originates from the nitrogen present in the coal itself. This form of NO_x is generated through complex chemical reactions that take place during combustion. Under normal circumstances, fuel-type NO_x accounts for approximately 80% to 90% of the total NO_x emissions, while high-temperature NO_x constitutes only about 10% to 20%.

Considering the dominance of fuel-type NO_x in the overall NO_x emissions, the primary focus in addressing NO_x pollution from coal combustion is on reducing the emission of fuel-type NO_x. Various techniques and technologies can be employed for this purpose, such as optimizing combustion conditions, improving burner design, implementing low-NO_x combustion technologies, and using selective catalytic reduction (SCR) or selective non-catalytic reduction (SNCR) systems to further reduce NO_x emissions.

By targeting the reduction of fuel-type NO_x, it is possible to mitigate NO_x pollution associated with coal combustion, despite the smaller contribution of high-temperature NO_x in solid slag pulverized coal furnaces. These efforts contribute to improving air quality and reducing the environmental impact of coal-fired power plants and other industrial facilities that rely on coal combustion processes [7].

9. Optimization Direction of Coal Use in the Future

9.1. Develop a Circular Economy for Coal

The circular economy represents a new growth model that prioritizes the efficient use and recycling of resources. It is based on the understanding of ecological laws and principles, aiming to minimize waste generation and maximize resource utilization. The circular economy recognizes the finite nature of natural resources and the limited environmental capacity to absorb waste and emissions. Therefore, it emphasizes the sustainable utilization of natural resources to ensure their availability for future generations and seeks to operate within the limits set by ecological laws. At the core of the circular economy are the principles of "reduction, reuse, and recycling." Reduction involves minimizing the consumption of resources and reducing waste generation. Reuse involves extending the lifespan of products through repair, refurbishment, or sharing models. Recycling involves the conversion of waste materials into secondary raw materials, reducing the need for extracting virgin resources. The circular economy model promotes "low development, low consumption, low emissions, and high efficiency." It encourages a shift away from the linear "take-make-dispose" economic model towards a more sustainable approach. This includes reducing the reliance on resource-intensive activities, adopting sustainable consumption patterns, minimizing emissions and pollution, and improving overall efficiency in resource use. Clean production practices are a fundamental aspect of the circular economy. It emphasizes the adoption of environmentally friendly manufacturing processes that minimize waste, emissions, and the use of hazardous substances. The development of ecological industries, such as renewable energy, sustainable agriculture, and waste management, aligns with the circular economy's principles. The ultimate goal of the circular economy is to achieve sustainable development. It recognizes that economic growth should not come at the expense of the environment and seeks to integrate economic, social, and environmental objectives. By embracing the circular economy, societies can strive for prosperity while preserving natural resources, reducing environmental impacts, and enhancing overall well-being for current and future generations [8].

9.2. CO_2 Capture Technology

The coal industry is investigating new technologies to reduce emissions of CO_2. Nowadays, one of the biggest challenges facing the coal industry worldwide is reducing CO_2 emissions from coal usage. The advancement of supercritical and ultra-supercritical steam cycle technologies is an important step in the combustion of coal (Miller, 2011). Another technology in reducing CO_2 emissions from coal utilization is the integrated gasification combined cycle (IGCC). This technology generates gas from coal for use in a gas turbine, rather than using direct coal combustion. It can use a broad band of different solid fuels with high efficiency. Furthermore, IGCC allows the possibility of carbon sequestration (Mondol et al., 2009). The most promising technology to reduce CO_2 emissions from coal usage is carbon capture and storage (CCS). Table 1 presents the CO_2 emissions (g/kWh) and efficiency (%HHV) of advanced power-generation technologies with and without CCS [9].

Table 1. Carbon dioxide (CO_2) emission (g/kWh) and efficiency (%HHV) of advanced power-generation technologies with and without carbon capture and storage (CCS).

	With			Without		
	Supercritical Pulverized coal	Ultra- supercritical Pulverized Coal	IGCC	Supercritical pulverized coal	Ultra- supercritical Pulverized Coal	IGCC
CO_2 emitted	109	94	101	830	738	824
Efficiency	29.3	34.1	31.2	38.5	43.4	38.4

9.3. Direct Liquefaction of Coal

The separation of inert solids associated with the coal feed is a necessary step within all direct coal liquefaction processes. In general, the lower the mineral matter content of the coal, the lower will be the capital and operating costs of the solids separation stage.

Hot, pressurized filtration is the solids separation method used within the British coal liquid solvent extraction (LSE) process. It is considered to be the most efficient of the methods available, since it rejects the smallest proportion of coal liquids with the solids. Nevertheless, there is scope for reducing this rejection stlfurther by reducing the total amount of solids which must be removed. Cleaning the coal prior to processing is an obvious means of achieving this.

Cleaning the feed coal may, however, have other effects on the economics of coal liquefaction. For example, some methods of coal cleaning preferentially reject unreactive coal macerals with the mineral matter. This could increase the extent to which the coal could be dissolved in the first stage, which in turn could change the filtration properties of the residual solids. The behavior of the dissolved coal 'extract' in the subsequent hydrocracking step could also be affected. The work described in this paper was designed to examine and to quantify these effects for the LSE process when coal cleaning was performed in a dense-medium centrifugal separator [10].

10. Conclusion

Clean energy is an international trend, and countries around the world have laid out renewable energy development plans according to their respective resource endowments, such as France's promotion of nuclear energy, and the UK's development of offshore wind power, all hoping to achieve clean energy. China is in the midst of a transition period from high carbon to low carbon and no carbon. As a matter of current trends, China's total energy demand will still increase, but it is not yet ready to achieve a full replacement of coal from renewable energy. However, the low-carbon development of the energy structure is still an important task. For the coal industry, a key point for future development is to give full play to the inherent advantages of coal chemical industry and produce products suitable for the characteristics of coal chemical industry. It should be noted that the goal of “carbon peaking” and “carbon neutrality” is not to ban carbon dioxide emissions, but to reduce carbon dioxide emissions while promoting carbon dioxide absorption and offsetting emissions with absorption. After the maturity of future technology, we will actively build a regional low-carbon clean energy supply system according to local conditions and promote the national energy revolution through the regional energy revolution on the basis of breakthroughs in key technologies to solve energy and environmental problems. Achieving the dual carbon emission target involves various industries of the national economy, the structural adjustment of the energy industry itself, the structural adjustment of other industries with the goal of improving efficiency and energy conservation and emission reduction, and even the scientific research and technology development model must be adjusted to give full play to the advantages of the national system. Only through top-level design and the joint efforts of the whole society can a benign model of sustainable development be formed.

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