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Status and Development Trends of Coal Mining Subsidence Areas in China

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ABSTRACT: Coal is the fundamental energy source and important industrial raw material in China. Since the founding of the People's Republic of China, cumulative raw coal production has exceeded 96 billion tons, providing a reliable energy guarantee for national economic and social development. However, after long-term development, most of the coal-rich blocks in the eastern region have entered the later stages of exploitation, resulting in a severe and unsustainable situation. Coal mining can lead to the destruction of land resources and the deterioration of the ecological environment, damage groundwater resources, exacerbate supply shortages in water-scarce areas, and cause emissions of waste gases, thereby harming the atmospheric environment. The large-scale mining and utilization of coal resources have played a significant role in driving our country's economic development; however, coal mining subsidence has also created a series of negative impacts on the human living environment. The ecological restoration and management of subsided mining areas are directly related to the sustainable development of the economy, society, and ecological environment in mining regions, posing an urgent problem that needs to be addressed in our country. The National Medium- and Long-Term Plan for Scientific and Technological Development (2006–2020) and the "12th Five-Year Plan" both prioritize the development of ecological protection and restoration technologies in mining areas, advocating the development of green mining and promoting the restoration of mine geological environments and land reclamation in mining areas. Therefore, comprehensive management of coal mining subsidence areas and the restoration of the ecological environment in mining areas will become one of the main research topics for mine workers in China in the coming years.

KEYWORDS: coal resources; coal mining subsidence areas; ecological environment; sustainable development

1.INTRODUCTION

After years of mining, coal resources in eastern China are gradually depleting, with increasingly complex mining conditions and rising production costs. In recent years, the center of China's coal mining industry has shifted westward. Most western mining areas are in arid and semi-arid regions with scarce water resources, sparse vegetation, and fragile ecosystems[1]. Compared with eastern mining areas, western coal resources have better occurrence conditions, mainly using mechanized fully mechanized caving mining, characterized by high yield, high efficiency, and high-intensity mining, which causes more severe disturbances to rock strata and the surface than general coal mining faces[2-3]. Coal mining has damaged groundwater runoff, lowered the groundwater table, and reduced surface water, leading to surface drought, soil erosion, desertification, and vegetation withering, further deteriorating the already fragile ecological environment. Environmental problems caused by coal mining in western arid and semi-arid regions have become a hot topic of social concern[4-5].

2. CURRENT STATUS OF COAL RESOURCE MINING IN CHINA

According to data from the Ministry of Natural Resources, China's proven coal reserves were 207.885 billion tons in 2021 and 207.012 billion tons in 2022, remaining almost unchanged year-on-year[6]. By region, in 2022, Shanxi, Inner Mongolia, Xinjiang, and Shaanxi ranked top four in coal reserves, with 48.31 billion tons, 41.122 billion tons, 34.186 billion tons, and 29.097 billion tons respectively, accounting for 73.77% of the national total.

The distribution of coal resources in China is broad, and the geological background of the formation and evolution of coal resources is diverse, and the main characteristics of the distribution of coal resources in China are in the north-south direction, bounded by the Qinling-Dabie Mountain orogenic belt, and there are many coal-bearing basins in the north and few in the south[7]. From east to west, the coal resources in the western Mengdong region are mainly concentrated in the Erlian Basin, and the three eastern provinces in the east, the coal resources are obviously sporadically distributed, and even the coal resources in the Daxing'an Mountains are almost non-existent, entering the extension area of the Taihang Mountains, the coal resources on both sides are more concentrated, and then to the south of Henan to the west of Hubei and Hubei and enter the blank area[8]. To the west, coal resources are still abundant on both sides of Liupan Mountain. Another characteristic is that there is often no distribution of coal resources in the vicinity of the orogenic belt, which is due to the fact that the orogenic belt formed in the early stage is usually used as a tectonic high part and a source supply area in the later stage of coal resource formation, and there is almost no coal accumulation[9]. Or the coal resources formed in the early stage were eroded in the process of the uplift of the orogenic belt in the later stage.

According to the National Bureau of Statistics, in 2022, the raw coal output of coal enterprises above designated size in the country will reach 4.50 billion tons, an increase of 370 million tons or 9.0% year-on-year. In 2022, the proportion of output in 100 million tons of coal-producing provinces will continue to increase[10]. The total raw coal output of the five provinces (regions) of Shanxi, Inner Mongolia, Shaanxi, Xinjiang and Guizhou was 3.768 billion tons, accounting for 82.64% of the total national output[11]. Among them, the cumulative output of raw coal in Shanxi, Inner Mongolia, Shaanxi and Xinjiang increased by 8.7%, 10.1%, 5.4% and 28.6% respectively year-on-year. The coal output of Fujian, Qinghai, Jiangxi, Shandong, Guizhou and Anhui provinces decreased by 17%, 15.6%, 8.3%, 6%, 4% and 0.9% respectively year-on-year.

Table 1 Raw Coal Output of Enterprises above Designated Size in China, 2022

Region	Output (100 million tons)	Year-on-Year Growth Rate	Proportion of National Raw Coal Output
Shanxi	13.07	8.7%	28.67%
Inner Mongolia	11.74	10.1%	25.75%
Shaanxi	7.46	5.4%	16.36%
Xinjiang	4.13	28.6%	9.05%
Guizhou	1.28	-4.0%	2.81%
Anhui	1.12	-0.9%	2.45%
Henan	0.98	4.2%	2.14%
Ningxia	0.94	8.4%	2.05%
Shandong	0.88	-6.0%	1.92%
Heilongjiang	0.7	8.4%	1.52%
Yunnan	0.67	9.6%	1.46%

According to data from the National Bureau of Statistics, from January to February 2024, coal production has declined while imports have increased rapidly. In January and February, the industrial raw coal output reached 710 million tons, a year-on-year decrease of 4.2%, compared to a 1.9% increase in December of the previous year; the average daily output was 11.75 million tons. Coal imports amounted to 74.52 million tons, marking a year-on-year growth of 22.9%, continuing to maintain a rapid growth rate.

Our country is entering a critical period of accelerated industrialization. With the transformation of the economic growth model of the coal industry and the expansion of coal's applications, the strategic significance of coal remains extremely important[12].

3. PROBLEMS FACED BY COAL MINING SUBSIDENCE AREAS

Subsidence areas cause significant impacts and damages to the agriculture, industry, ecological environment, and people's lives around mining areas. To achieve sustainable development of the coal mining industry, subsidence area issues must be resolved[13]. With economic and social development, coal mining volume will increase, leading to greater disasters in the environment, land, water resources, and buildings caused by subsidence areas.

3.1 Damage to Land Resources

Severe soil erosion, significant vegetation destruction, decline in soil fertility, and a reduction in arable land are occurring. The changes in the hydrological and geological environment of coal mining subsidence areas have led to alterations in local soil fertility, resulting in decreased land productivity, and in some cases, complete loss[14-15]. Previously irrigated lands have transformed into dry and thin soils. The decrease in cultivated land area has exacerbated the conflicts between population and land, as well as between coal and agriculture. Additionally, land subsidence has increased surface slopes and disrupted the relatively stable soil structure. Mining-induced subsidence has caused surface deformation, forming surface movement basins, leading to ground fissures and sinkholes, thereby damaging the original surface morphology. Changes in surface slope alter existing runoff patterns; with steeper slopes resulting in increased runoff, the associated soil erosion and loss of topsoil become more severe[16]. The emergence of surface fissures allows for the infiltration of surface water and groundwater into deeper layers, causing a decline in the water table and resulting in reduced soil moisture, rendering the land increasingly arid.

3.2 Impact on Hydrological Environment

During the coal mining process, on one hand, the extensive discharge from the mines leads to a rapid decline in underground water levels; on the other hand, untreated mine water seeps back underground, resulting in contamination of groundwater. Due to mining subsidence, the surface exhibits forms of damage such as sinkholes, cracks, and depressions, which to some extent alters the runoff and catchment conditions of surface precipitation[17]. This allows surface water to infiltrate underground through the cracks, causing a reduction in river system flow, and in severe cases, even leading to the interruption of surface water systems. During the subsidence process, the overburden rock layers of the coal system are damaged, resulting in an increase in fissures within the strata. The aquifer in the overburden layers of the coal system is interfered with in terms of water level and flow direction. As a result, groundwater accelerates towards the mined-out areas or deeper rock masses along the developed fissures, leading to a reduction in water levels. In severe cases, this can result in groundwater drainage and the drying up of wells and springs. The destruction of water sources directly impacts the water supply for agricultural and industrial production in the mining area, as well as the water necessary for residents' daily lives.

3.3 Impact on Vegetation

Underground coal mining causes damage to the overburden from below to above, leading to the formation of fracture zones within the rock layers and cracks on the surface. In the loess hilly areas, subsidence due to coal mining not only alters the elevation and gradient of the land but also, influenced by topographical conditions, can lead to surface disasters such as landslides and collapses. The various damages caused by mining to the overburden and the surface result in the loss of both surface water and groundwater, thereby causing soil erosion and soil degradation, which ultimately affects surface vegetation and crops. The direct impact of subsidence due to mining on plants and crops is that the root systems of these plants and crops, located on the mining-induced fractures, collapses, and landslides, are exposed or severed; some are even buried or have fallen into the fractures and subsidence pits. The indirect impact arises from the changes in soil structure, moisture, and temperature caused by surface subsidence and fractures[18]. Water, soil, and fertilizers can be lost through these fractures, leading to a deterioration of the growth environment for plants and crops, which, over a certain period, can affect the growth of plants and the yield of crops to varying degrees.

4 GREEN MINING STRATEGIES

Green mining technologies mainly include water-preserving coal mining, simultaneous extraction of coal and gas, gangue reduction, subsidence reduction mining, and environmental restoration technologies. The focus of technology application should be targeted based on the resource and environmental conditions and problems of different mining areas.

4.1 Water-Preserving Coal Mining Technology

The research and implementation of water resource protection and utilization technologies in the coal mining process (i.e., water-preserving mining technology) are crucial prerequisites for achieving green mining in coal mines. Due to the movement and disruption of the mined rock strata, the extraction of coal inevitably disturbs the underground water bodies. This disturbance can lead to changes in the elevation and flow direction of the aquifer's bottom boundary at minor levels, and in severe cases, it may result in the destruction or even drainage of water bodies[19]. When the influx of water from damaged water bodies is significant, it can trigger a flooding disaster in the mine. Therefore, maintaining water preservation in coal mining should encompass the following four levels of connotation: Firstly, it is essential to prevent water-influx accidents at the coal mining face, ensuring safe and efficient extraction; Secondly, technical measures should be implemented to minimize or avoid damage to the aquifer caused by coal mining, thereby protecting groundwater resources; Thirdly, artificial restoration or measures that promote natural self-restoration should be undertaken for aquifers damaged by mining activities, facilitating the aquifer's return to its original storage state; Fourthly, there should be a resource utilization of the water resources lost during mining activities (i.e., mine drainage), to some extent achieving "coal-water co-extraction."

4.2 Simultaneous Extraction of Coal and Gas Technology

In traditional coal mining, coal seam gas is regarded as a hazardous gas due to its explosion risk and coal-gas outburst potential. Additionally, as a clean energy source, coal seam gas can be used for residential life, power generation, and industrial raw materials. Direct emissions of large amounts of coal seam gas waste energy resources and severely pollute the atmosphere, as methane has a greenhouse effect 20 times greater than carbon dioxide. Therefore, extracting and utilizing gas as a resource is the fundamental solution.

More than 95% of the high-gas and outburst coal mines in our country exploit low-permeability coal seams, which exhibit poor gas drainage effects. Enhancing the permeability of these coal seams is key to addressing this issue. The coal seams are classified as non-through fractured rock masses, characterized by very complex structural and mechanical properties. To increase their permeability, it is necessary to modify the low-permeability coal body. Currently, there are two methods to improve the permeability of coal seams. The first method involves altering the mechanical state of the gas-containing coal body to induce plastic failure, thereby opening existing fissures and creating new ones. The second method applies various physical fields to the gas-containing coal seams, such as microwaves, acoustic vibrations, etc., which help generate new fractures in the gas-containing coal body under the influence of these physical fields, consequently enhancing the permeability of low-permeability coal bodies[20].

4.3 Backfilling and Subsidence Reduction Mining Technology

The issue of subsidence control primarily involves the extraction of coal beneath buildings, which has been a significant technical challenge faced by coal mines in our country, particularly in the eastern mining areas that are densely populated and economically developed. Traditional longwall mining methods have caused severe damage to the surface and buildings, while relocation mining methods face extreme difficulties due to high costs and implementation challenges, resulting in a sharp conflict between building subsidence related to coal extraction and mining operations. Therefore, subsidence-reducing mining technology has become an important component of green mining. Partial mining and filling mining are the two main technical approaches for subsidence-reducing mining[21]. The former involves leaving a portion of coal pillars to support the overlying rock and control surface subsidence, while the latter utilizes man-made structures to support the overlying rock, thus reducing the number of coal pillars to improve extraction rates. In our country, the partial mining method primarily consists of strip mining, which is an early method for coal extraction under buildings. However, due to the small allowable working face width (generally <50 m), low extraction rates (<50%), and low production efficiency, the application of this method has gradually decreased.

5 COMPREHENSIVE MANAGEMENT AND RESTORATION

5.1 Exploring New Technologies and Models for Comprehensive Management of Coal Mining Subsidence Areas

It is necessary to strengthen refined management of coal mining subsidence areas, adopt corresponding ecological protection and restoration technologies for different regions, and seek new models to improve economic, ecological, and social benefits. For example: ecological construction technologies for dynamic mining subsidence areas in western arid and semi-arid fragile regions; technologies for mining-induced water environment damage and reconstruction of aquifer (and aquitard); and optimized ecological restoration technologies for stable, cold mining subsidence areas in northeastern China.

5.2 Conducting a National Census of Coal Mining Subsidence Areas

After a decade of rapid mining, the basic situation of coal mining subsidence areas is still unclear. Especially, after the country implemented the orderly closure of backward production capacity mines, 1,052 coal mines needed to be closed in 2015.

5.3 Initiating the Preparation of Comprehensive Management Plans, Relevant Mechanisms, and Standards for Coal Mining Subsidence Areas

Make full use of resources in coal mining subsidence areas, encourage the integration of comprehensive management with new urban and rural construction, allow the combination of comprehensive management with urban commercial development, coordinate the costs of subsidence area management and relocation of affected villages, and balance subsidence area governance expenditures with urban commercial development revenues.

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