

# Research on the Current Status and Development Trends of Coal Mine Gas Drainage Technology

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## Abstract

**This paper systematically reviews the evolutionary trajectory of coal mine gas drainage technology, with a focus on analyzing the principles, methodologies, and application status of key technologies, including gas drainage in high-permeability coal seams, pressure-relief gas drainage in adjacent seams, enhanced gas drainage in low-permeability coal seams, and comprehensive gas drainage approaches. Research indicates that with continuous technological advancements, the efficiency of gas drainage has significantly improved. However, challenges persist, such as the difficulty in extracting gas from low-permeability coal seams and the high precision requirements for drilling operations. Future development trends include the integration of intelligent drainage systems, novel permeability-enhancing technologies, the adoption of green mining concepts, and the collaborative optimization of multiple technologies. This study provides technical references and developmental insights for gas management and resource utilization in coal mines.**

## Keywords

**Coal Mine Gas; Drainage Technology; High-Permeability Coal Seam; Low-Permeability Coal Seam; Pressure-Relief Drainage; Comprehensive Drainage; Technological Development.**

## 1. Introduction

Coal mine gas (coalbed methane, CBM), as an unconventional natural gas resource coexisting with coal, poses a significant threat to the safety of coal mine production while simultaneously representing a valuable clean energy source [1-3]. With the in-depth promotion of China's strategic goals of "carbon peaking" and "carbon neutrality," the importance of coal mine gas drainage technology, as a key means to ensure safe coal mine production and improve resource utilization efficiency, has become increasingly prominent [4-5]. According to statistics from the National Energy Administration, the national coal mine gas drainage volume reached 13.5 billion cubic meters in 2024, with a utilization rate of 44.4%, representing an increase of 2.85 percentage points compared to 2023. However, there is still a significant gap compared to developed countries. Meanwhile, as the depth of coal mining continues to increase at a rate of 10-15 meters per year, the high in-situ stress and high geothermal environment under deep mining conditions pose new challenges to traditional gas drainage technologies [6].

From the perspective of technological development, China's coal mine gas drainage technology has undergone an evolutionary process from passive treatment to active utilization, and from single-method approaches to comprehensive systems. From the 1950s to the 1970s, gas drainage was mainly carried out in high-permeability coal seams within the same coal seam. From the 1980s to the 1990s, pressure-relief gas drainage technology in adjacent seams was

widely applied. Entering the 21st century, breakthroughs were made in enhanced gas drainage technologies for low-permeability coal seams, represented by hydraulic fracturing. In recent years, comprehensive drainage systems based on the synergistic integration of multiple technologies have become the mainstream development direction. This technological evolution reflects profound changes in China's coal mine gas management philosophy and engineering practices.

Currently, research on coal mine gas drainage technology faces several key scientific and technical challenges: in terms of basic theory, the gas migration mechanism under multi-field coupling conditions remains unclear. And in terms of engineering technology, the long-term permeability-enhancing effects in deep low-permeability coal seams are difficult to sustain. And in terms of system optimization, the design of drainage schemes under complex geological conditions lacks precise guidance. These issues severely constrain the further improvement of gas drainage efficiency, necessitating systematic technical summarization and analysis of development trends [7]. Researching the current status and development trends of coal mine gas drainage technology holds significant theoretical value and practical significance. At the theoretical level, summarizing the laws of technological development can refine the theory of coalbed methane migration and production, providing directional guidance for subsequent technological innovations. At the practical level, optimizing drainage schemes for different coal seam conditions can effectively enhance gas drainage efficiency and reduce the risk of coal mine safety accidents. Additionally, with advancements in gas utilization technologies, the utilization of 100 million cubic meters of methane is equivalent to reducing carbon dioxide emissions by 1.5 million tons, making a significant contribution to achieving the "dual carbon" goals. Furthermore, the technological systems and methodologies developed in this study can serve as references for the development of unconventional natural gas under similar conditions.

## 2. Gas Drainage Technology in High-Permeability Coal Seams

Gas drainage in high-permeability coal seams represents the earliest stage of gas drainage technology development, primarily targeting geological conditions with relatively high coal seam permeability. In such coal seams, the resistance to gas flow is relatively low, enabling conventional drainage methods to achieve satisfactory results. This stage primarily employs two technical approaches: roadway drainage and borehole drainage [8].

Roadway drainage involves the construction of dedicated drainage roadways within the coal seam, utilizing negative pressure to extract desorbed gas from the seam. This method offers a large drainage area and stable performance but entails significant engineering workloads and high costs. A typical application example is the roadway grid layout system employed in the No. 15 coal seam of the Yangquan Mining Area, which achieved a pre-drainage efficiency of over 60% for gas. Borehole drainage, on the other hand, involves drilling vertical or inclined boreholes into the coal seam and connecting them to a drainage system for gas collection. This method is highly flexible, allowing for adjustments to borehole parameters based on coal seam conditions. For instance, the large-diameter borehole cluster layout adopted in the Huabei Mining Area achieved a single-borehole drainage rate of 3-5 m<sup>3</sup>/min. The main advantages of gas drainage technology in high-permeability coal seams lie in its relatively simple process and rapid effectiveness. However, it also faces technical challenges such as large-scale roadway construction and borehole collapse susceptibility. With increasing mining depths, maintaining roadway stability and borehole formation rates under high in-situ stress conditions have become new challenges. The drainage theories and engineering experiences developed during this stage have laid the foundation for subsequent technological advancements, with their core principles still being applied in various drainage methods today.

### 3. Pressure-Relief Gas Drainage Technology in Adjacent Seams

As mining practices have advanced, engineers have observed that the extraction of a coal seam induces pressure relief in the adjacent upper and lower seams, prompting gas from these seams to migrate towards the mining area. Based on this phenomenon, pressure-relief gas drainage technology in adjacent seams has emerged [9-10]. The key to this technology lies in the rational layout of drainage boreholes to capture the gas released within the pressure-relief zone.

Depending on the occurrence conditions of the coal seam group, pressure-relief drainage in adjacent seams can be categorized into two modes: upper adjacent seam drainage and lower adjacent seam drainage. Upper adjacent seam drainage typically employs cross-seam boreholes, with drilling conducted from the mining seam roadway into the upper seam, as exemplified by the drainage layout for the No. 5 coal seam during the extraction of the No. 3 coal seam in the Jincheng Mining Area. Lower adjacent seam drainage often utilizes floor roadways in conjunction with upward boreholes, such as the "one roadway with multiple boreholes" layout system adopted in the Huainan Mining Area. In optimizing drainage parameters, factors such as seam spacing, lithology, and drainage negative pressure are prioritized to ensure that boreholes penetrate the pressure-relief fracture development zone. The technical advantage of pressure-relief drainage in adjacent seams lies in its ability to achieve "one extraction for multiple seams," significantly enhancing gas management efficiency. Typical application results indicate that a reasonably arranged adjacent seam drainage system can intercept 60-80% of the gas from adjacent seams, substantially reducing the risk of gas overrun in the mining face. However, this technology exhibits poor adaptability to geological conditions, with its effectiveness being limited in areas with significant variations in coal seam group spacing or poor rock stratum stability. Additionally, precise control of the final borehole position is a critical technical challenge in ensuring drainage effectiveness.

### 4. Enhanced Gas Drainage Technologies in Low-Permeability Coal Seams

The majority of coal seams in China are classified as low-permeability, where conventional drainage methods exhibit low efficiency. To address this, various enhanced drainage technologies have been developed. Hydraulic fracturing technology involves creating a fracture network within the coal seam using high-pressure water to improve gas seepage pathways [11-12]. This technology has achieved favorable applications in the Qinshui Basin, Shanxi Province, where the coal seam permeability coefficient increased by 10-50 times post-fracturing. Deep-hole pre-splitting blasting technology utilizes explosive energy to generate radial fractures. Applications in the Hebi Mining Area have demonstrated that the influence radius of boreholes post-blasting can reach 8-15 meters.

CO<sub>2</sub> displacement technology is based on the principle of competitive adsorption between CO<sub>2</sub> and CH<sub>4</sub>, enabling both enhanced gas drainage rates and CO<sub>2</sub> sequestration [13]. Data from the Pingdingshan pilot area in Henan Province indicate that single-borehole gas drainage volumes increased by 3-5 times after CO<sub>2</sub> injection. Additionally, novel permeability-enhancing technologies such as pulsating hydraulic fracturing and supercritical CO<sub>2</sub> fracturing are showing promising prospects in the experimental stage. The main challenges faced by enhanced gas drainage in low-permeability coal seams include high technical costs, complex processes, and insufficient sustainability of permeability-enhancing effects. Particularly under deep high in-situ stress conditions, artificial fractures are prone to re-closure, affecting drainage performance. Future research should focus on long-term permeability-enhancing mechanisms and the optimization of low-cost processes.

## 5. Integrated Gas Drainage Technologies

Integrated gas drainage technologies represent the mainstream direction of modern coal mine gas management, with the core concept of combining multiple drainage methods to form a three-dimensional drainage network based on coal seam conditions and mining stages [14-18]. Typical models include the "trinity" system of "in-seam drainage + adjacent seam drainage + goaf drainage," such as the "combined surface and underground" drainage system established in the Songzao Mining Area.

In terms of technological integration, integrated drainage emphasizes spatiotemporal collaborative optimization. Spatially, it achieves coordinated development of coalbed methane and coal resources, while temporally, it covers the entire cycle of pre-mining drainage, during-mining drainage, and post-mining drainage. The multi-level three-dimensional drainage system applied in the Sihe Coal Mine in Jincheng has achieved a gas drainage rate exceeding 85%. The introduction of intelligent control technologies has further enhanced system responsiveness, such as real-time monitoring and automatic pressure regulation systems based on the Internet of Things. The technical advantages of integrated drainage lie in its ability to adapt to complex geological conditions and maximize gas management effects. However, the system is highly complex, requiring precise design and strict management. Particularly under conditions of combined mining in multiple coal seams, the optimization of drainage schemes poses significant challenges. Future development directions include cutting-edge fields such as intelligent drainage decision-making systems and multi-field coupling simulation technologies.

## 6. Development Trend Analysis

The main challenges faced by current coal mine gas extraction technology include: the impact of high ground stress and high geothermal environment on the extraction system under deep mining conditions; The durability issue of the anti permeability effect of low-permeability coal seams. The precise design challenge of extraction schemes under complex geological conditions. And the balance between extraction costs and benefits. These issues constrain the further improvement of gas extraction efficiency.

The future development of technology will present the following trends: towards intelligence, intelligent extraction systems based on the Internet of Things and big data will achieve real-time monitoring, automatic regulation, and optimized operation. The application of new materials and technologies, such as nano enhancers and supercritical fluid fracturing, will break through the limitations of traditional technologies. Under the concept of green mining, multiple resource collaborative development models such as gas extraction, carbon sequestration, and geothermal development will be developed. Interdisciplinary integration and cross innovation in fields such as geological engineering, fluid mechanics, and information technology will drive innovation in pumping technology. Of particular note is that digital twin technology is expected to achieve virtual simulation and optimization of gas extraction systems, and artificial intelligence algorithms can enhance the adaptive adjustment ability of extraction parameters. The application of these cutting-edge technologies will lead gas extraction into a new stage of intelligence. Meanwhile, with the advancement of the "dual carbon" target, the innovation of gas resource utilization technology will form a positive interaction with the progress of extraction technology.

## 7. Conclusion

This article systematically reviews the development history of coal mine gas extraction technology, and provides a detailed analysis of the principles, methods, and application characteristics of key technologies at each stage. Research has shown that the evolution from a

single extraction method to a comprehensive extraction system reflects the shift of gas control concepts from passive prevention and control to active utilization. Although current technology has achieved significant results, it still faces many challenges in deep mining and complex geological conditions.

The future development of gas extraction technology should focus on the following directions: firstly, strengthening basic theoretical research and deeply revealing the gas migration laws under multi field coupling conditions. The second is to promote technological innovation, develop efficient and low-cost transparency enhancement methods and intelligent control systems. The third is to improve the standard system, establish extraction technical specifications and evaluation methods that are suitable for different geological conditions. The fourth is to promote interdisciplinary integration and draw on new technologies and methods from other fields to drive innovation in extraction technology. With the advancement of technology and the improvement of management level, coal mine gas extraction will develop towards a more efficient, intelligent, and environmentally friendly direction, making greater contributions to coal mine safety production and clean energy utilization. It is suggested to strengthen the cooperation between industry, academia and research, accelerate the transformation of scientific and technological achievements, and focus on talent cultivation to provide sustained impetus for the innovation of gas extraction technology.

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