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Current Research Status and Development Trends of Mine Ventilation Technology in China

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Abstract

Mine ventilation is a crucial safeguard for safety in mine production. This paper provides an in-depth analysis of the current development status and future trends of mine ventilation technology in China. By reviewing the technological evolution, intelligent transformation practices, breakthroughs in key technologies, and the effectiveness of industry applications, it reveals the core values of mine ventilation systems in ensuring safety, enhancing energy efficiency, and promoting green development. Combining policy guidance, market demands, and directions of technological innovation, the paper indicates that future mine ventilation technology will evolve towards deep intelligence, full-factor digitization, and green and low-carbon development. Furthermore, it proposes development suggestions such as strengthening basic research, improving standard systems, and cultivating interdisciplinary talents, providing theoretical support for promoting safe and efficient mining operations in China.

Keywords

Mine Ventilation; Technological Status; Development Trends; Intelligence; Digitization; Green Mine.

1. Introduction

As the global mining resource development accelerates towards deeper and more intelligent directions, the mine ventilation system, as the core infrastructure ensuring safe mine production, has its technological development level directly influencing the safety of mine working environments, resource extraction efficiency, and the effectiveness of ecological and environmental protection [1-2]. As the world's largest coal producer and consumer, China holds a pivotal position for coal in its energy structure. Technological innovations and breakthroughs in mine ventilation serve as a solid foundation for the smooth implementation of the national energy security strategy and a core driving force for promoting high-quality development in the mining industry.

In recent years, the deep integration of next-generation information technologies such as the Internet of Things (IoT), big data, and artificial intelligence (AI) has brought revolutionary changes to mine ventilation systems. Ventilation systems are transitioning from mechanization to intelligence, achieving autonomous perception, intelligent decision-making, and precise control; evolving from single-function to system integration, operating collaboratively with other mine systems; and shifting from high energy consumption to green and low-carbon operations, reducing energy losses and environmental impacts [3-5]. Based on this, this paper will systematically review the development trajectory of mine ventilation technology in China, thoroughly analyze the bottlenecks and challenges currently faced in technological applications, closely align with industry policy directions and changes in market demand, and prospectively explore future technological development trends and innovation pathways, providing a solid theoretical reference for constructing a safe, efficient, and green modern mine ventilation system.

2. Development History of Mine Ventilation Technology in China

2.1. Mechanization Infrastructure Construction Phase (1950–2000)

In the early days of the founding of the People's Republic of China, mine ventilation technology in China was in its infancy, primarily relying on the introduction of Soviet technology and independent imitation. In 1953, the Fushun Mining Bureau successfully developed the country's first axial flow fan, marking the beginning of the localization process for mine ventilation equipment in China. By the 1980s, with the large-scale development of the coal industry, mine ventilation systems gradually formed a technical system dominated by mechanical ventilation supplemented by local ventilation. During this period, the technological characteristics were manifested as follows: ventilation equipment mainly consisted of axial flow and centrifugal fans, ventilation methods were primarily extraction and forced ventilation, and ventilation network design mainly relied on empirical formulas and manual calculations. In the 1990s, with the introduction of computer technology, mine ventilation network calculation software began to be applied in engineering practice. However, due to limitations in hardware performance and algorithm accuracy, real-time dynamic control capabilities remained relatively weak.

2.2. Digital Upgrade Phase (2000–2015)

Entering the 21st century, mine ventilation technology in China entered a fast track of digital upgrades. In 2002, the State Administration of Work Safety issued the "Coal Mine Safety Regulations," explicitly requiring that mines must establish a complete mechanical ventilation system and be equipped with monitoring devices for parameters such as wind speed, air pressure, and gas. Driven by this policy, mine ventilation systems began to integrate sensor networks, data acquisition terminals, and monitoring platforms, enabling real-time monitoring and remote transmission of ventilation parameters. Around 2010, with the maturity of industrial Ethernet technology, mine ventilation monitoring systems gradually developed towards distributed and networked directions. Some large coal mines began pilot projects to construct digital twin models of ventilation systems, laying the foundation for subsequent intelligent transformation. Technological breakthroughs during this phase were mainly reflected in the following aspects: the monitoring accuracy of ventilation parameters was improved to ±0.1 m/s, data transmission delay was controlled within 5 seconds, and the calculation speed of ventilation network solutions increased to the minute level.

2.3. Intelligent Transformation Phase (2015–Present)

In 2015, the State Council issued the "Guidelines on Actively Promoting the 'Internet Plus' Action," explicitly proposing to promote intelligent transformation in the mining industry. Against this backdrop, mine ventilation technology entered an accelerated phase of intelligent transformation. In 2018, the National Coal Mine Safety Administration released the "Guidelines for Intelligent Construction of Coal Mines," listing intelligent ventilation systems as one of the core subsystems of intelligent coal mines. In 2024, the "Whole-Mine Intelligent Ventilation System" independently developed by the Coal Research Institute of the China Coal Technology and Engineering Group was successfully applied in the Chahasu Coal Mine, achieving breakthroughs in four major functions: real-time perception of ventilation parameters, dynamic calculation of ventilation networks, intelligent decision-making on ventilation strategies, and remote control of ventilation facilities. As of 2025, over 70 mines across the country have completed intelligent ventilation system transformations, with the market size of intelligent ventilation equipment exceeding 4.5 billion yuan and an annual compound growth rate of 28%.

3. Analysis of the Current Status of Mine Ventilation Technology in China

Currently, China has made remarkable progress in mine ventilation technology in terms of theoretical research, technical equipment, and engineering applications.

(1) In terms of theoretical research, China has established a mature mine ventilation theoretical system, covering core contents such as ventilation network theory, airflow patterns, and ventilation resistance calculations [6-9]. Modern numerical simulation methods, such as Computational Fluid Dynamics (CFD), are widely applied in the analysis and optimization design of ventilation systems, significantly enhancing the scientific accuracy and precision of designs. Zhang Haishun [10] discovered through simulation analysis that the airflow in China's fully mechanized mining faces generally exhibits a pattern of "smaller on both sides and larger in the middle," with two peak zones of wind speeds exceeding 3.5 m/s on either side of the shearer, which has a critical impact on the dust distribution in fully mechanized mining faces. Meanwhile, key breakthroughs have also been achieved in cutting-edge areas such as complex ventilation network solutions and unsteady-state ventilation simulations, laying a solid theoretical foundation for the development of ventilation technology. Tan Guowen [11] studied the visual dynamic solution of complex mine ventilation networks, with the system's calculated air volume showing an error of less than 10% compared to the actual air volume. Zhang Mingguang et al. [12] developed an unsteady-state simulation solution system for roadway ventilation networks, applicable to both forced and natural ventilation network simulations.

(2) In terms of technical equipment, China has developed the capability to independently manufacture various types of mine ventilation equipment. High-efficiency and energy-saving main fans, local fans, and their associated control systems have reached or approached international advanced standards [13]. The successful application of variable frequency drive technology in fans has significantly enhanced the regulatory performance and energy efficiency of ventilation systems. Additionally, the localization of supporting equipment such as mine sensors and automatic air doors [14] has provided strong support for the construction of complete and efficient ventilation control systems.

(3) In terms of engineering applications, automated and intelligent ventilation systems have been widely promoted in large-scale mines. Mine ventilation monitoring and control systems based on IoT technology can collect key parameters such as air volume, wind speed, and gas concentration in real-time and enable automatic adjustment of the ventilation system through intelligent algorithms [15]. Digital twin technology has begun to be applied in ventilation system management, facilitating fault prediction and optimization decision-making by constructing virtual ventilation systems [16]. In special-condition mines such as high-gas mines and deep high-temperature mines, targeted ventilation technologies and solutions have effectively addressed safety production challenges and ensured the safety of mine operations.

However, the development of mine ventilation technology in China still faces numerous challenges. First, the technical standard system is incomplete, with varying levels of ventilation technology application across different regions and scales of mines. Second, there is a shortage of professional technical talent, particularly compound professionals who are proficient in both ventilation theory and modern information technology. Third, reliance on imported equipment and technologies for certain key components remains, highlighting the need to strengthen independent innovation capabilities. Fourth, the energy consumption issue of ventilation systems is prominent, with untapped potential for energy conservation. These issues severely constrain the further development of mine ventilation technology in China and urgently require resolution through technological innovation and management optimization.

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4. Development Trends of Mine Ventilation Technology in China

In the future, China's mine ventilation technology will align with the development trends of the times and make significant strides towards intelligence, digitization, green development, and multi-functional integration, ushering in a new chapter of development.

(1) Intelligence stands as the core driving force and trend in the development of mine ventilation technology. With the rapid advancements in artificial intelligence technology, ventilation systems are gradually transitioning from traditional passive control to proactive intelligent decision-making. The deep learning-based ventilation parameter prediction model, akin to a "wise oracle" well-versed in the laws of mine ventilation, can accurately predict the dynamic changes in ventilation parameters, such as gas concentration, wind speed, and temperature, through in-depth analysis of massive amounts of historical and real-time monitoring data, providing forward-looking scientific basis for ventilation control. The intelligent optimization algorithm, like a "master scheduler" with exceptional skills, automatically generates the optimal ventilation plan based on the prediction results and actual operating conditions and enables real-time dynamic adjustments to ensure that the ventilation system always operates at its best. The intelligent air volume distribution system possesses the ability to "adapt to changing circumstances," swiftly and precisely optimizing the air supply to each ventilation point based on real-time changes in mining layouts and the distribution of workers, effectively improving ventilation efficiency and reducing energy consumption.

(2) Digital technology will be deeply integrated into every aspect of mine ventilation, constructing a precisely interactive digital ecosystem. Digital twin technology will create more accurate virtual models of ventilation systems, enabling real-time interaction and synchronous optimization between the physical and digital systems, allowing managers to conduct comprehensive simulations, analyses, and optimizations of the ventilation system in the virtual world. 5G communication technology, with its exceptional characteristics of large bandwidth and low latency, provides a solid foundation for the real-time transmission and processing of massive ventilation data, ensuring smoother and more efficient data flow. Big data analytics technology, like a "data detective," delves deep into the hidden potential patterns within the operational data of the ventilation system, offering comprehensive and accurate data support for ventilation management decisions. Blockchain technology is expected to make significant contributions in the field of ventilation safety management, with its immutable and fully traceable characteristics ensuring the authenticity and integrity of ventilation data and providing reliable technological means for ventilation safety supervision.

(3) Green development represents an important direction for mine ventilation technology to align with the trends of the times. Energy conservation and consumption reduction will become one of the core indicators in the design of ventilation systems, with mature technologies such as high-efficiency fans, variable frequency drives, and waste heat recovery being more widely applied and further optimized to reduce energy consumption at the source. The introduction of renewable energy sources such as solar and wind power will inject green momentum into mine ventilation systems, reducing reliance on traditional energy sources and lowering carbon emissions. Green and environmentally friendly materials will gradually replace traditional ventilation structure materials, minimizing the impact of mine ventilation systems on the environment and achieving harmonious coexistence between mining development and environmental protection. Additionally, the ventilation system will be collaboratively optimized with systems for mine heat hazard control and dust suppression to achieve multi-objective environmental control, creating a comfortable and healthy working environment for miners.

(4) Multi-functional integration is a prominent feature in the development of mine ventilation technology. Future mine ventilation systems will no longer be limited to the single function of

providing fresh air but will integrate multiple functions such as environmental monitoring, emergency shelter, and energy recovery. Ventilation roadways may simultaneously undertake tasks such as cable laying and pipeline arrangement, significantly improving the utilization of underground space. The ventilation system will also be deeply integrated with the mine IoT platform, becoming an important component of smart mines and enabling interconnected and intelligent management of equipment. Under deep mining conditions, the ventilation system will be collaboratively designed with cooling systems and support systems to form a comprehensive underground environmental control system, providing reliable technological support for deep mining.

5. Conclusion

After more than 70 years of development, China's mine ventilation technology has formed a relatively complete technical system and achieved remarkable breakthroughs in intelligent transformation. Facing new challenges such as deep mining and green and low-carbon development, future technological advancements will exhibit three major trends: deep intelligence, full-factor digitization, and green and low-carbonization. Through measures such as strengthening fundamental research, improving standard systems, cultivating professional talent, and optimizing the industrial ecosystem, China's mine ventilation technology is expected to achieve leapfrog development during the 15th Five Year Plan period, providing solid support for building a safe, efficient, and green modern mining industry system.

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