

Research Status and Development Trends of Intelligent Ventilation Technology in Coal Mine

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Abstract: Coal mine ventilation is a core aspect of ensuring safe production in coal mines, and its intelligent development holds significant importance for enhancing coal mine safety, efficiency, and sustainability. This paper elaborates in detail on the current technological status of intelligent ventilation technology in coal mines across various aspects, including intelligent perception of ventilation parameters, intelligent control of ventilation facilities and equipment, intelligent decision-making in ventilation techniques, optimized design of ventilation systems, maintenance and management of ventilation equipment, as well as ventilation supervision systems and technical standards. It also analyzes the existing problems and challenges. Meanwhile, it looks ahead to the development trends of intelligent ventilation technology in coal mines in terms of technological innovation, system integration, industry convergence, green energy conservation, and international cooperation, providing a reference for further research and application of intelligent ventilation technology in coal mine.

Keywords: Intelligent ventilation in coal mine; intelligent perception of ventilation parameters; intelligent control of ventilation facilities and equipment; intelligent decision-making in ventilation techniques; optimized design of ventilation systems.

1. Introduction

Coal mine ventilation, as a critical safeguard measure in the coal mining process, plays a vital role in ensuring the life safety of miners and maintaining the normal production order of mines [1-3]. During coal mining, harmful gases such as methane and coal dust are generated. Meanwhile, as the mining depth increases, the impact of geothermal factors on the mine environment becomes more pronounced [4-5]. A good ventilation system can promptly discharge these harmful gases, introduce fresh air, reduce the temperature and humidity inside the mine, and create a safe and comfortable working environment for miners [6-7].

However, traditional coal mine ventilation technologies have numerous limitations. Traditional ventilation systems mainly rely on manual operations and empirical judgments, making it difficult to grasp the ventilation conditions inside the mine in real-time and accurately. They cannot adjust ventilation parameters promptly according to actual situations, resulting in poor ventilation effects and even potentially triggering safety accidents. Additionally, traditional ventilation systems have certain issues in terms of energy consumption and equipment maintenance, making it challenging to meet the requirements of modern coal mines for efficient, safe, and green production [8-10].

With the rapid development of intelligent technologies, applying them to the field of coal mine ventilation has become an effective way to solve the problems of traditional ventilation technologies. Coal mine intelligent ventilation technology achieves real-time monitoring and analysis of ventilation parameters, intelligent control of ventilation facilities and equipment, and intelligent decision-making in ventilation techniques by integrating advanced technologies such as sensors, the Internet of Things, big data, and artificial intelligence. It can significantly improve the operational efficiency and safety of coal mine ventilation systems, reduce energy consumption and operational costs, and is of great

significance for promoting the intelligent transformation and sustainable development of the coal mine industry [11-14]. Therefore, it is necessary to systematically review the research progress of coal mine intelligent ventilation technology, conduct in-depth analysis of its development status, and proactively explore future trends to provide certain references for its development.

2. Research Status of Coal Mine Intelligent Ventilation Technology

2.1. Intelligent Perception Technology of Ventilation Parameters

Intelligent perception of ventilation parameters is the foundation of coal mine intelligent ventilation systems. It achieves precise measurement of key parameters such as wind speed, air pressure, temperature, humidity, and methane concentration by deploying various sensing devices in underground roadways [15]. Currently, China's coal mines have made certain progress in intelligent perception of ventilation parameters. Many coal mine enterprises have added or improved existing ventilation monitoring equipment, such as installing high-precision wind speed sensors, differential pressure sensors, temperature and humidity sensors, and methane sensors, enabling accurate monitoring of key parameters in the ventilation network. For example, the "Intelligent Ventilation System for the Entire Mine" independently developed by the China Coal Research Institute, affiliated with China Coal Technology and Engineering Group, has been successfully applied in the Chahasu Coal Mine. This system effectively integrates cutting-edge sensor technologies, enabling real-time capture and precise analysis of mine ventilation parameters. These sensors can collect data in real-time and transmit it to the ground monitoring center through industrial ring networks, providing reliable data support for intelligent decision-making of the ventilation system. Some mines have also

added automatic full-cross-sectional airflow measurement devices in roadways, replacing the work of wind measurement personnel and further improving the accuracy and efficiency of ventilation parameter measurement.

In terms of wind measurement methods, some coal mines have made innovations. For instance, the intelligent ventilation system designed by Caojiatan Coal Mine adopts large-distance ultrasonic wind measurement technology to measure the "linear wind speed" in the main roadway, collecting the average wind speed passing through the underground roadway cross-section. From the wind speed data, the "surface wind speed" in the underground roadway can be derived, greatly avoiding the phenomena of one-sided and large-deviation wind speed measurements in traditional wind measurement methods and improving accuracy. The ultrasonic anemometer adopts the time-difference ultrasonic speed measurement principle, utilizing the different timeliness of sound waves flowing downstream and upstream in the fluid and the relationship between the sound wave transmission distance and speed within the same time to judge the average wind speed in the roadway.

2.2. Intelligent Control Technology of Ventilation Facilities and Equipment

Intelligent control of ventilation facilities and equipment is the core of coal mine intelligent ventilation systems. It achieves intelligent management of the ventilation system through remote automatic control of ventilation facilities and equipment such as air doors, air windows, main fans, and local fans [16-18]. Currently, China's coal mines have conducted extensive research and practice in intelligent control of ventilation facilities and equipment. Many coal mine enterprises have added equipment and systems such as remote control of ventilation equipment, remote automatic control of air doors and air windows. Through PLC technology and variable frequency speed regulation facilities, they have achieved remote control of ventilation facilities and equipment and air volume regulation. For example, remote-controlled air doors have real-time monitoring functions such as switch status monitoring, infrared vehicle and personnel monitoring, and sound-light alarms. They can be automatically controlled through hydraulic transmission. Air door control adopts electro-hydraulic control, with functions such as anti-pinching, air door interlocking, and automatic reset, effectively improving the safety and automation level of air doors. Meanwhile, based on PLC technology, the mine intelligent ventilation system can also set the operating frequency of variable frequency speed regulators and remotely adjust the operating frequency of underground variable frequency speed regulators through underground monitoring sub-stations, thereby achieving air volume regulation of local fans and ensuring the stable and reliable operation of the underground ventilation system.

In terms of remote control of air windows, the intelligent ventilation system of Caojiatan Coal Mine is equipped with electric air doors and electric adjustable air windows. The air doors are connected to the air door centralized controller through air door controllers, and the air windows are connected to the air window transfer controller through air window controllers. The air door centralized controller directly communicates with the air window transfer controller. The air window transfer controller collects information on the operating status and sensor data of air windows and air doors,

uploads it to the system server through the network, receives instructions issued by the system server, and forwards them to the corresponding air window controllers and air door controllers to achieve automatic adjustment of air windows and air doors.

2.3. Intelligent Decision-Making Technology of Ventilation Techniques

Intelligent decision-making of ventilation techniques is the key to coal mine intelligent ventilation systems. It analyzes and processes real-time monitoring data of ventilation parameters and, combined with the actual situation and ventilation requirements of the mine, provides a scientific basis for the operation adjustment of the ventilation system [19]. Currently, China's coal mines have achieved some research results in intelligent decision-making of ventilation techniques. Some coal mine enterprises have utilized big data analysis, artificial intelligence, and other technologies to construct ventilation network solution models, achieving dynamic solution of the ventilation system and rapid generation of airflow distribution schemes.

For example, the Scott-Hinsley wind network air volume solution method is used for ventilation network solution to obtain the full wind network air volume. Through software deployed on servers, an intelligent ventilation management and control system integrating management, control, early warning, analysis, and decision-making is formed, which can grasp the operating status of the ventilation system in real-time, promptly discover ventilation hazards, and automatically provide adjustment schemes. Meanwhile, some enterprises have also integrated ventilation data with environmental monitoring parameters, achieving effective integration of data with data and data with graphics, providing intelligent decision-making means for disaster prevention and control early warning. The "Intelligent Ventilation System for the Entire Mine" independently developed by the China Coal Research Institute, affiliated with China Coal Technology and Engineering Group, has a built-in intelligent auxiliary decision-making module that can automatically adjust and optimize ventilation strategies according to the actual working conditions of the mine, effectively ensuring the stable and efficient operation of the mine ventilation system. Especially in emergency situations, the system can immediately initiate an emergency response mechanism, building a solid defense line for mine safety.

2.4. Optimization Design Technology of Ventilation Systems

Optimization design of ventilation systems is an important means to improve the ventilation effect of coal mines and reduce ventilation costs [20]. Currently, China's coal mines have accumulated rich experience in the optimization design of ventilation systems. Many coal mine enterprises have optimized the ventilation system from aspects such as equipment layout, ventilation process reduction, ventilation capacity verification, and monitoring point layout adjustment according to the actual situation of the mine.

In terms of equipment layout, a multi-fan and multi-stage fan station layout method is adopted. According to the internal needs of the mine, ventilation devices are reasonably arranged to accelerate the wind transmission speed during the production operation process and improve the ventilation effect. In terms of ventilation process reduction, based on the internal structure of the mine, the ventilation sub-segment

process of roadways is scientifically designed to simplify the ventilation process, reduce the loss of air volume under the action of the ventilation process, and minimize wind pollution phenomena, ensuring that the air indicators inside the mine meet the standards. In terms of ventilation capacity verification, according to the production and operation situation of the mine, the ventilation capacity is accurately verified, and reasonable fan device models are selected to ensure that the ventilation system matches the actual production operation requirements of the mine. In terms of monitoring point layout adjustment, according to the actual performance of the mine structure and ventilation system, monitoring points are scientifically arranged, and computer technology and modern communication technology are utilized to achieve real-time monitoring and analysis of the operating parameters of the ventilation system.

2.5. Maintenance and Management Technology of Ventilation Equipment

The normal operation of ventilation equipment is the key to ensuring the safe and reliable operation of coal mine ventilation systems [21]. Currently, China's coal mines have formulated a series of management systems and technical measures for the maintenance and management of ventilation equipment. Many coal mine enterprises have established regular inspection and maintenance systems for ventilation equipment, regularly conducting patrol inspections, maintenance, and repairs of ventilation equipment, promptly discovering and eliminating equipment faults, and ensuring the normal operation of equipment. Meanwhile, they have strengthened the training and management of ventilation equipment operators, improving their skill levels and sense of responsibility, and reducing equipment faults caused by improper operations.

2.6. Ventilation Supervision System and Technical Standards

A perfect ventilation supervision system and technical standards are an important guarantee for ensuring the safe operation of coal mine ventilation systems [22]. Currently, China has gradually established a relatively complete ventilation supervision system and technical standards for coal mines. The Standardization Administration of China and relevant industry associations have jointly issued multiple national standards and industry standards, covering aspects such as ventilation system design, equipment selection, and operation and maintenance, providing important guidance and constraints for the technological research and development, product manufacturing, construction and installation, and operation management of coal mine ventilation systems. Meanwhile, coal mine safety supervision departments at all levels have strengthened supervision and inspection of coal mine ventilation systems, severely cracking down on ventilation violations, and ensuring the safe operation of coal mine ventilation systems.

3. Challenges Facing the Development of Intelligent Ventilation Technology in Coal Mines

(1) High Barriers to Technology Integration and Application

Intelligent ventilation technology in coal mines involves the deep integration of multiple advanced technologies,

including the Internet of Things (IoT), big data, artificial intelligence (AI), cloud computing, and edge computing. However, the complexity and variability of the mine environment necessitate a high degree of stability and reliability in the technology. In practical applications, challenges arise regarding the compatibility and collaborative working capabilities of different technologies, making integration difficult. For example, sensor technology must adapt to harsh underground conditions such as high temperatures, humidity, and dust to ensure accurate data collection and stable transmission. Big data and AI algorithms must process vast amounts of real-time data and perform rapid, accurate analysis and decision-making, placing high demands on computational power and algorithm optimization.

(2) Data Security and Privacy Protection Issues

The data generated by intelligent ventilation systems in coal mines contains a large amount of sensitive information, such as ventilation parameters, equipment operating status, and mine geological structures. If this data is leaked or misused, it poses significant risks to coal mine operations, such as ventilation system malfunctions caused by malicious attacks, which could even lead to safety incidents. Currently, there are weak links in data security and privacy protection, including inadequate data encryption technologies, lax access control strategies, and a lack of awareness about data security.

(3) Talent Shortage

The development of intelligent ventilation technology in coal mines relies on highly skilled professionals. However, there is currently a relative shortage of professionals in related fields, particularly those with a dual understanding of coal mine ventilation technology and intelligent technologies. The talent cultivation system is not well-developed, with universities and vocational schools falling short in meeting actual demands in terms of professional setup and curriculum design, resulting in graduates lacking in practical and innovative abilities. Additionally, coal mine enterprises have limited appeal to talent due to relatively harsh working conditions, modest salaries, and limited career development prospects, leading to a serious issue of talent drain.

(4) Insufficient Funding

The research, development, application, and maintenance of intelligent ventilation technology in coal mines require substantial financial investment. From the purchase and installation of sensing devices to the development of intelligent control systems and the optimization of ventilation systems, significant financial support is needed. However, some coal mine enterprises, especially small and medium-sized ones, struggle to afford the high costs of intelligent ventilation technology upgrades due to poor economic performance and limited financial resources. Insufficient funding restricts the promotion and application of intelligent ventilation technology, preventing the timely introduction and application of advanced equipment and technologies, thereby impeding the intelligent upgrading process of coal mine ventilation systems.

4. Development Trends of Intelligent Ventilation Technology in Coal Mines

4.1. Technological Innovation Trends

(1) Advancement of Sensor Technology Towards High Precision, High Reliability, and Intelligence

With the increasing requirements for ventilation parameter

monitoring in intelligent coal mine ventilation technology, sensor technology is progressing towards high precision, high reliability, and intelligence. In the future, more sensors with high sensitivity, strong stability, and intelligent analysis capabilities will emerge to adapt to complex underground environments and achieve precise monitoring of ventilation parameters. Smart sensors will not only collect data in real-time but also conduct preliminary analysis and automatically alert abnormal conditions, with a clear trend towards miniaturization and integration for easier installation and deployment.

(2) Deeper Application of AI Technology in Ventilation Decision-Making

AI technologies, such as machine learning and deep learning, will play a greater role in ventilation decision-making. By learning from large amounts of ventilation data, AI algorithms can automatically identify system operating modes and potential risks, providing a scientific basis for ventilation decision-making. For example, deep learning can be used to optimize ventilation network calculation models, while machine learning can predict and diagnose faults, enabling preventive maintenance of ventilation equipment. Additionally, AI can achieve adaptive control of ventilation systems, automatically adjusting ventilation parameters based on changes in the mine environment to improve operational efficiency and safety.

(3) IoT Technology Enabling Comprehensive Interconnection of Ventilation Equipment

IoT technology will drive the comprehensive interconnection of ventilation equipment. By installing IoT modules, ventilation equipment can achieve data sharing and collaborative work, improving overall efficiency and reliability. At the same time, IoT technology enables remote monitoring and management, reducing manual inspection workloads and improving management efficiency. Managers can use IoT platforms to grasp equipment operating status and fault information in real-time, facilitating timely maintenance and repairs.

(4) Big Data Technology Supporting Ventilation System Optimization

Big data technology will store, manage, and analyze the vast amounts of data generated by ventilation systems, providing strong support for system optimization. By deeply mining and analyzing ventilation data, system issues and potential risks can be identified, providing a basis for decision-making in optimization design, equipment selection, and operational adjustments. For example, big data can be used to analyze energy consumption, identify energy-saving transformation links, assess ventilation effects, and provide references for optimization adjustments. Additionally, big data technology can be combined with machine learning algorithms to achieve intelligent prediction and optimized control.

(5) Construction of a Unified Intelligent Mine Management and Control Platform

In the future, coal mines will construct a unified intelligent mine management and control platform that integrates ventilation systems, safety monitoring systems, production scheduling systems, etc., to achieve centralized data management and sharing. Managers can use this platform to grasp the operating status of various systems in real-time, conduct unified scheduling and management, and also realize data analysis and mining to support production decision-making.

4.2. Industry Integration Trends

The development of intelligent ventilation technology in coal mines cannot be achieved without the support of the equipment manufacturing industry. In the future, both sides will achieve coordinated development, with equipment manufacturing enterprises researching, developing, and producing more intelligent and efficient ventilation equipment. Coal mine enterprises will strengthen cooperation with equipment manufacturing enterprises to jointly carry out technological research and product innovation. Coal mine enterprises will also enhance cooperation with research institutions and universities to jointly conduct research and development of intelligent ventilation technology in coal mines. Research institutions and universities will provide theoretical support and technological innovation, while coal mine enterprises will provide practical application scenarios and data, realizing the deep integration of industry, academia, research, and application.

4.3. Green and Energy-Saving Trends

With the increasing requirements for energy conservation and emission reduction, intelligent ventilation technology in coal mines will place greater emphasis on energy conservation. In the future, there will be increased research and application of energy-saving ventilation equipment, such as highly efficient and energy-saving main fans and local fans, adopting advanced frequency conversion speed regulation technologies and aerodynamic designs to reduce energy consumption. By optimizing the operation strategies of ventilation systems, energy conservation and consumption reduction can be achieved. For example, dynamically adjusting the operating parameters of ventilation equipment based on actual mine production conditions and ventilation needs; adopting technologies such as zonal ventilation and on-demand ventilation to reduce unnecessary ventilation energy consumption; and utilizing a combination of natural and mechanical ventilation to lower mechanical ventilation energy consumption.

4.4. International Cooperation Trends

There is a gap between China's intelligent ventilation technology in coal mines and international advanced levels. In the future, China will strengthen cooperation with international advanced enterprises, introduce foreign advanced technologies and management experiences, and improve the level of China's intelligent ventilation technology in coal mines. At the same time, with the development of China's intelligent ventilation technology in coal mines, China will actively participate in the formulation of international standards, enhance its voice and influence in the international field of intelligent ventilation in coal mines, and promote the internationalization of China's intelligent ventilation technology in coal mines.

5. Conclusion

Intelligent ventilation technology in coal mines is an important means to ensure safe production and improve production efficiency in coal mines. Currently, China's intelligent ventilation technology in coal mines has made certain progress in areas such as intelligent perception of ventilation parameters, intelligent control of ventilation facilities and equipment, and intelligent decision-making of ventilation technology. However, there are still some issues,

such as the need to improve the accuracy and stability of sensors, difficulties in integrating ventilation facilities and equipment, and insufficient accuracy of intelligent decision-making models for ventilation technology. Meanwhile, the development of intelligent ventilation technology in coal mines also faces challenges such as high barriers to technology integration and application, data security and privacy protection issues, talent shortages, and insufficient funding.

In the future, intelligent ventilation technology in coal mines will develop in the directions of technological innovation, system integration, industry integration, green energy conservation, and international cooperation. By continuously researching and applying new technologies, improving the accuracy and reliability of ventilation parameter monitoring, realizing the intelligent control and collaborative work of ventilation facilities and equipment, optimizing the design and operation of ventilation systems, strengthening integration with other industries, promoting the application of green and energy-saving technologies, and enhancing international cooperation, China's intelligent ventilation technology in coal mines will continuously improve its level, providing strong support for the intelligent transformation and sustainable development of the coal mine industry.

References

- [1] Chu Zonghui, Hou Kai, Zhao Shuguo, et al. Research Status and Development Direction of Coal Mine Ventilation Technology [J]. *Science and Technology & Innovation*, 2024, (16): 126-128.
- [2] Hu Xiao, Wang Ning. Optimization and Intelligent Management of Coal Mine Ventilation Systems [J]. *Industry and Mine Automation*, 2024, 50(S2): 33-34 + 56.
- [3] Wang Hao, Liu Jialin, Wang Qinghai. Exploration of the Application of Intelligent Ventilation Technology in Gas Control in Coal Mines [J]. *Inner Mongolia Coal Economy*, 2025, (06): 163-165.
- [4] Li Yanhe, Zhao Wanli, Yu Zhenzi, et al. Analysis of Heat Sources and Temperature Field Evolution Laws in High-Temperature Coal Mining Faces in Deep Mines [J]. *China Coal*, 2024, 50(05): 59-67.
- [5] Guo Huaiguang. Research and Discussion on the Inducing Mechanism of Gas Dynamic Disasters in Deep Coal Seams [J]. *China Coal*, 2023, 49(05): 43-49.
- [6] Xu Haidong, He Shudong, Su Mingqiang, et al. Precise Early Warning of Coal Mine Disasters and the Architecture and Construction Content of Intelligent Mine Ventilation Systems [J]. *Energy and Environmental Protection*, 2025, 47(03): 1-10.
- [7] Jia Xiaolong. Application and Development Trends of Coal Mine Ventilation Systems [J]. *Energy and Energy Conservation*, 2024, (04): 307-310.
- [8] Li Xuelin. Existing Problems and Solutions for Ventilation Gas Safety in Coal Mines [J]. *Energy and Energy Conservation*, 2024, (07): 65-67.
- [9] Meng Long. Discussion on the Current Status and Prospects of the Development of Ventilation Technology and Equipment in China's Coal Mines [J]. *Inner Mongolia Coal Economy*, 2021, (10): 147-148.
- [10] Lin Qingsong. Current Status and Prospects of the Development of Ventilation Technology and Equipment in China's Coal Mines [J]. *Inner Mongolia Coal Economy*, 2020, (08): 165.
- [11] Wang Qiang. Design of an Automatic Control System for Coal Mine Ventilation Based on Big Data Technology [C]//Guangxi Network Security and Informatization Federation. Proceedings of the 6th Academic Exchange Conference on Engineering Technology Management and Digital Transformation. Shanxi Ningwu Dayun Huasheng Nangou Coal Industry Co., Ltd.; 2025: 322-324.
- [12] Lu Jianbo, Mei Yangyang. Design and Implementation of a Coal Mine Ventilation System Based on Reinforcement Learning [J]. *Automation Application*, 2024, 65(24): 73-75.
- [13] Liang Jun. Research on a Rapid Determination Method for the Friction Resistance Coefficient of Ventilation Roadways Based on Big Data [J]. *Energy and Environmental Protection*, 2024, 46(04): 51-55.
- [14] Yang Bo. An Automatic Control System for Coal Mine Ventilation Based on Big Data Analysis [J]. *Energy and Environmental Protection*, 2023, 45(08): 39-44.
- [15] Wang Yanjun. Construction of an Intelligent Perception System for Ventilation Parameters in Gucheng Coal Mine [J]. *Mining Equipment*, 2023, (06): 152-155.
- [16] Gao Ruoyang. Research on an Intelligent Frequency Conversion and Monitoring System for Underground Ventilation in Coal Mines [J]. *Mechanical Engineering & Automation*, 2025, 54(02): 191-193.
- [17] Song Yunlong. Transformation and Application of Intelligent Air Door Control Technology in Pangpangta Coal Mine [J]. *Intelligent Mine*, 2024, 5(10): 81-84.
- [18] Huang Yongqi. Research on Precise Calculation of Air Volume Through Air Windows in Liuzhuang Mine and the Intelligent Control and Management System for Air Doors and Windows [D]. *Anhui University of Science and Technology*, 2024.
- [19] Wang Bin, Liu Zunli, Du Jianhua, et al. Research on Intelligent Decision-Making and Dynamic Control Technologies for Mine Ventilation Systems [J]. *Inner Mongolia Coal Economy*, 2022, (13): 72-74.
- [20] Li Hu. Optimization Design and Energy-Saving Analysis of Underground Ventilation Systems in Coal Mines [J]. *Energy and Energy Conservation*, 2025, (05): 91-93.
- [21] Miao Yi. Optimization of the Operation and Maintenance of Coal Mine Ventilation Systems [J]. *Energy and Energy Conservation*, 2023, (09): 219-221.
- [22] Zou Yinhui, Ju Guangang. Research on Standards for Ventilation Equipment in China's Coal Mines [J]. *China Coal*, 2022, 48(06): 75-79.