

Research on Anti-Blowout Devices for Gas Drainage Boreholes

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Abstract: Coal remains one of the world's most critical energy sources. As coal demand continues to rise, mining intensity increases, and the challenges of gas prevention and control grow increasingly complex. Traditional blowout prevention technologies face numerous limitations. Addressing safety hazards caused by gas blowouts during underground coal mine gas extraction operations, this study analyzes the mechanisms of coal and gas outbursts and reviews blowout prevention technologies. Building upon existing blowout prevention devices, an innovative blowout prevention device for gas extraction boreholes was designed and researched. This device primarily consists of a wellhead blowout preventer, a gas-water-slurry dynamic separation unit, a discharge mechanism, and a monitoring system. It achieves fully enclosed, negative-pressure, high-efficiency gas extraction alongside efficient separation and discharge of gas, water, and slurry.

Keywords: Blowout Prevention Hole; Gas Extraction; Dynamic Separation; Efficient Discharge.

1. Introduction

Gas drainage is currently the primary method for preventing and controlling gas disasters in coal mining. However, the effectiveness of gas drainage in Chinese coal mines remains suboptimal, with approximately 65% of the gas extraction concentrations in longwall mining faces falling below 30% [1]. Due to complex geological conditions, high gas content, and substantial gas pressure in mines, blowout incidents are prone to occur during gas drainage processes. Such incidents can not only result in significant economic losses, resource wastage, and environmental pollution but also pose risks of poisoning and injury to personnel.

Currently, there is extensive research on anti-blowout devices for gas drainage both domestically and internationally. For instance, Mu Chaoyuan et al. [2] employed a "borehole orifice pipe-PVC steel wire hose" configuration, effectively controlling gas leakage at the borehole opening. Li Peng achieved rapid activation of anti-blowout devices by deploying sensors near boreholes to detect early signs of blowouts [3]. Research on gas borehole anti-blowout devices began earlier abroad, with a stronger emphasis on investigating the intrinsic mechanisms of gas outbursts during coal mine drilling operations, thereby laying a solid theoretical foundation for the development of such devices. For example, Du F et al. [4], while studying nitrogen-injection-enhanced coalbed gas extraction (N₂-ECGE), analyzed variations in parameters such as gas pressure and content. Their work revealed patterns related to coal seam permeability, indirectly providing insights into gas outburst mechanisms and guiding the adaptive design of anti-blowout devices. Similarly, Gongda W et al. [5] focused on the mechanism of coal fragmentation induced by supersonic gas jet impact. Given the close relationship between coal fragmentation and gas outbursts during drilling, their analysis of the coal fragmentation process under impact aids in predicting gas outburst risks. This, in turn, offers theoretical

support for determining the response timing and structural strength requirements of anti-blowout devices.

In summary, research on anti-blowout devices for gas drainage has achieved significant progress both domestically and internationally. However, current existing devices still suffer from several shortcomings, such as incomplete separation of gas, water, and solid residues, which leads to partial discharge of gas alongside wastewater and slag—resulting in environmental pollution. Additionally, issues such as overly complex device structures and inadequate sealing performance remain prevalent. To address the aforementioned issues, the blowout preventer designed for this project is an integrated sealing-and-collection device. The sealing mechanism employs a three-stage sealing system. The three-stage system operates synergistically, with each stage complementing the others to significantly enhance the overall sealing performance. This effectively prevents gas leakage, thereby mitigating the risk of explosions or fires caused by gas accumulation. As a result, it substantially improves mining safety and safeguards the lives of personnel.

2. Design Philosophy of the Anti-Blowout Device for Gas Drainage Boreholes

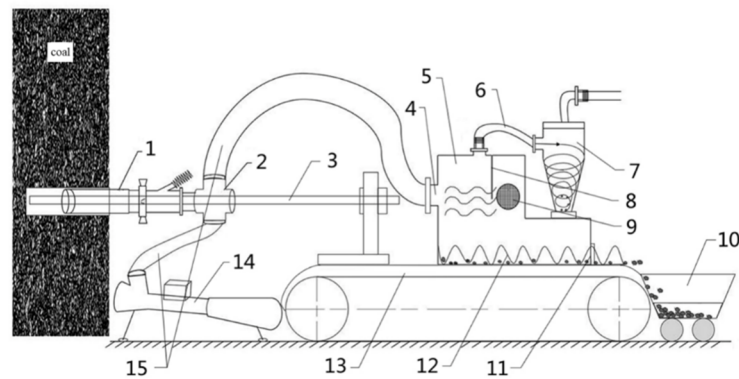
Building upon traditional designs, the conventional borehole blowout prevention device has been optimized and improved. Guided by the principles of safety, efficiency, airtightness, and environmental sustainability, an integrated design framework has been established for the overall apparatus. The developed anti-blowout device for gas drainage boreholes is illustrated in Fig. 1.

Characteristics of the Gas Drainage Borehole Anti-Blowout Device:

The blowout prevention sleeve is installed around the drill pipe with a gap between them. The interior of the sleeve is equipped with bristles that remain in contact with the surface of the drill pipe. Externally, the sleeve is fitted with a thrust

ring and a rubber tube, which forms a sealed contact with the borehole wall in the coal seam. The sidewall of the sleeve is provided with a branch pipe and an inflatable bladder. The

outlet end of the blowout prevention sleeve is connected to a four-way connector, with the opposite end of the connector linked to a conveyance pipe.



1. Blowout preventer sleeve; 2. Four-way connector; 3. Drill pipe; 4. Feed inlet; 5. Separation tank; 6. Extraction pipe; 7. Cyclone separator; 8. Baffle plate; 9. Drain outlet; 10. Coal slag collection bin; 11. Ash discharge port; 12. Screw blades; 13. Crawler assembly; 14. Jet nozzle; 15. Conveying pipe.

Figure 1. Schematic of the Anti-blowout Device for Gas Drainage Boreholes

This conveyance pipe is then connected to the feed inlet, which directs the mixture extracted from the borehole into the separation system. The feed inlet leads to the separation chamber, where the gas-phase outlet is connected to an extraction pipe. This extraction pipe feeds into a cyclone separator barrel. Within the separation chamber, flow baffles are installed to assist in the separation process, and a water drain outlet is extended from the sidewall of the chamber. The

solid-phase outlet of the cyclone separator barrel is connected to a helical blade conveyor, which transports the solid residues into the coal slag collection bin. The helical blade is mounted on a crawler track assembly, with its discharge end positioned above the coal slag collection bin. A jet injector is connected at one end to the conveyance pipe and at the other end to the crawler track assembly.

The design workflow of the device is illustrated in Fig. 2.

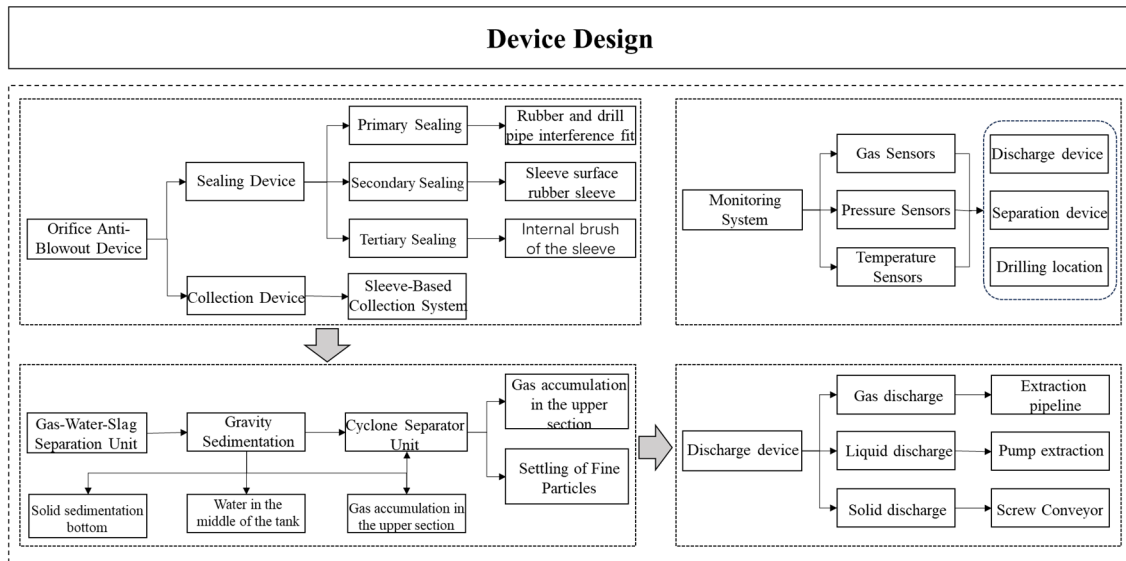


Figure 2. Flowchart of Device Design Process

The gas drainage borehole anti-blowout device is functionally and procedurally divided into four modules: the borehole anti-blowout system, the separation system, the discharge system, and the monitoring system.

(1) Borehole Anti-Blowout System: A high-efficiency anti-blowout sleeve has been designed and developed. It achieves comprehensive sealing between the drill rod and the borehole, as well as between the borehole and the surrounding rock wall, at the source. This effectively isolates the multiphase mixtures (such as gas, water, and waste residue) that erupt during drilling, preventing them from causing blockages in the drilling operation area. The device is capable of preventing gas accumulation from exceeding safe thresholds under conditions of high gas concentration. This significantly

reduces the probability of gas outburst incidents, thereby ensuring the safety of mining operations.

(2) Separation System: A gas-water-slurry separation tank has been designed, employing a combined approach of gravity sedimentation and centrifugal separation. This design enables the efficient separation and graded recovery of gas, liquid, and solid waste residues. It significantly enhances the efficiency and precision of the solid-liquid-gas three-phase separation process. This ensures that the various phase substances can be separated efficiently within a short period, thereby improving the overall operational efficiency and processing capacity of the system.

(3) Discharge System: Equipped with helical blades, a slag discharge port, and a water discharge port, the gas-water-

slurry separation tank facilitates the stratified discharge of solid waste, liquid effluent, and gas. This design achieves efficient three-phase media separation and environmentally sound treatment. It ensures the classified discharge of solids, liquids, and gases based on their respective media types, enabling the rational utilization of resources and preventing secondary pollution. Concurrently, the system effectively mitigates potential safety hazards, thereby safeguarding the safety and sustainability of the operational environment.

(4) Monitoring System: This system is designed for the real-time surveillance of the device's operational status to ensure both safety and efficiency during the gas drainage process. The monitoring apparatus is required to measure key

parameters, including methane concentration, flow rate, negative pressure, temperature, and carbon monoxide (CO) concentration within the gas drainage pipeline.

The types, functions, and installation locations of the various sensors are detailed in Table 1.

3. Development of the Anti-Blowout Sleeve Device

During the process of coal seam drilling, the dynamic changes in formation pressure are often accompanied by the sudden release of gas and the influx of coal cuttings and formation water.

Table 1. Sensor Type, Function, and Installation Location

Sensor Type	Function	Installation Location
CH ₄ Sensor	Real-time monitors the methane concentration in gas drainage pipelines and boreholes to prevent explosions.	At the pipeline of borehole outlet, and the junction of drainage branch pipes
CO Sensor	Monitors the presence of carbon monoxide (CO) during gas drainage.	In the middle of the pipeline
Pressure Sensor	Monitors pressure fluctuations to ensure a reasonable negative pressure in the gas drainage pipeline.	10–15 cm away from the orifice, and in front of the drainage pump inlet
Temperature Sensor	Monitors the gas temperature during drilling to prevent spontaneous combustion or mechanical overheating.	At the orifice sealing device
Liquid Level Sensor	Monitors the liquid water level in the tank to prevent liquid backflow or blockage, and ensures the separation effect at the same time.	Gas-water-slag separation tank

An integrated "sealing-collection" anti-blowout sleeve device is designed to address these challenges. On one hand, it achieves dynamic sealing of the borehole collar, preventing the disorderly leakage of gas and fluid media. On the other hand, it performs preliminary capture and diversion of the escaping gas, coal particles, and water influx concurrently

with the drilling operation, providing the necessary conditions for subsequent treatment.

A schematic diagram of the anti-blowout sleeve structure is shown in Figure 2, and an exploded view is presented in Fig. 3.

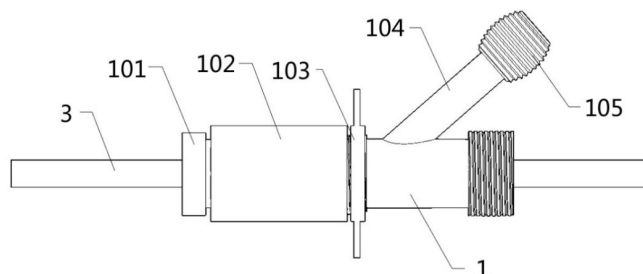


Figure 3. Structural Diagram of the Anti-Blowout Sleeve

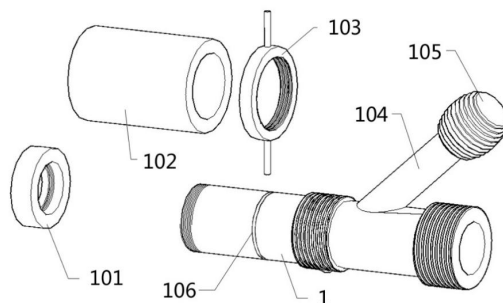


Figure 4. Exploded View of the Anti-Blowout Sleeve

101. Retaining Ring; 102. Rubber Sleeve; 103. Thrust Ring; 104. Branch Pipe; 105. Airbag; 106. Fixing Ring.

3.1. Device Features

The anti-blowout sleeve is mounted on the drill rod surface, maintaining a clearance gap between the drill rod and the sleeve. The interior of the sleeve is equipped with bristles that remain in tight contact with the drill rod surface to enhance the sealing effect. The exterior of the sleeve is fitted with a

thrust ring and a rubber sleeve, which ensures close contact with the wall of the coal seam borehole, thereby providing effective sealing. Additionally, a branch pipe and an expandable airbag are integrated into the sidewall of the anti-blowout sleeve, serving to provide supplemental pressure relief and enhance operational safety.

3.2. Working Principle

Sealing Operation:

Upon completion of the drilling operation, the anti-blowout sleeve is installed on the drill rod surface with a clearance gap between them, forming an interference fit to achieve the primary sealing effect.

The thrust ring is threadedly connected to the sleeve's exterior surface and is capable of moving axially along it. The rubber sleeve is fitted over the anti-blowout sleeve. By advancing the thrust ring, the rubber sleeve is compressed to form a tight seal against the coal seam wall, achieving the secondary sealing effect.

Bristles are designed on the inner wall of the anti-blowout sleeve. These bristles are densely arranged radially along the inner wall of the fixing ring, with their tips in contact with the drill rod surface. When the drill rod is inserted into the sleeve, the bristles conform closely to the rod, effectively blocking the passage of coal debris particles and achieving the tertiary sealing effect.

A detailed illustration of the bristle arrangement is shown in Fig. 5.

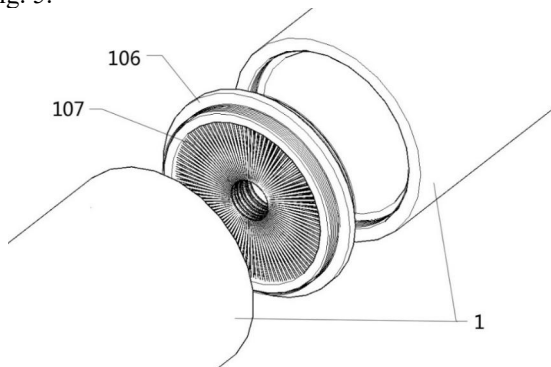


Figure 5. Schematic Diagram of the Sleeve Bristles
107. Bristles.

A branch pipe is also installed on the sidewall of the anti-blowout sleeve, equipped with an airbag that serves as the device's pressure relief safety unit. During drilling operations, if an excessive outburst of gas causes abnormal pressure buildup, the airbag can absorb the pressure shock through elastic deformation, thereby achieving effective pressure release. This prevents damage to the sleeve and connected pipelines due to overpressure, ensuring the operational safety of the entire anti-blowout system.

Collection Operation:

The gas, wastewater, and solid waste generated during drilling enter the interior of the anti-blowout sleeve immediately upon formation for initial containment. They are then conveyed through the system pipeline to subsequent gas-water-slurry separation and processing units.

4. Development of the Gas-Water-Slurry Separation Tank Device

The three-phase mixture, preliminarily collected by the anti-blowout sleeve and conveyed to the separation tank via the system pipeline, exhibits complex composition and unstable discharge characteristics. This can easily lead to issues such as incomplete separation, secondary pollution, and pipeline clogging. The integrated "graded purification-directed diversion" gas-water-slurry separation tank addresses these challenges by enabling efficient separation and deep purification of the three-phase media through synergistic multi-mechanisms, thereby improving the purity of extracted gas. Simultaneously, it facilitates the directed collection and regulated diversion of each separated phase, providing essential support for subsequent resource utilization and environmentally sound treatment.

A structural diagram of the gas-water-slurry separation tank is shown in Fig. 6.

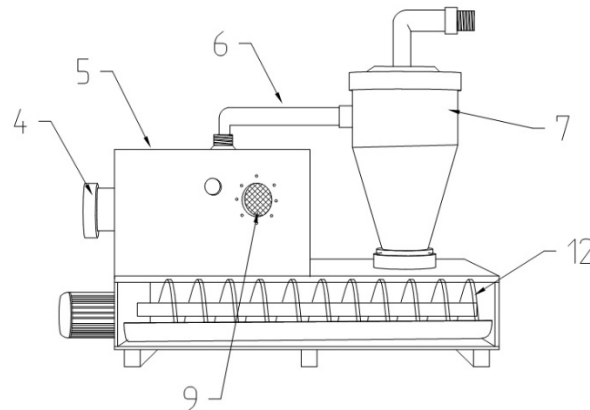


Figure 6. Structural Diagram of the Gas-Water-Slurry Separation Device

The gas-water-solid separation device is mainly composed of two parts: the box body and the swirling separation barrel.

4.1. Core Separation Mechanisms

Buffer and Flow Stabilization Mechanism: The feed pipe is internally equipped with a multi-layer flow guide structure. In coordination with baffles located in the upper-middle section of the separation tank, this attenuates the kinetic energy of the flowing three-phase mixed medium, homogenizes the flow regime, prevents separation disturbances caused by sudden velocity changes, and ensures stable conditions for subsequent graded separation.

Gravity-Based Graded Separation Mechanism: Leveraging

the natural density differences between gas, water, and slurry, distinct layers form. Larger solid particles settle to the bottom of the tank via gravity and are discharged by a screw conveyor. The liquid phase accumulates in the middle section and is pumped out. The gas phase, enriched by upward migration, is directed into a cyclone separator via a negative pressure extraction pipe for further purification.

Cyclonic Centrifugal Separation Mechanism: Inside the cyclone separator, the gas forms a rotational flow field. The generated centrifugal force flings the entrained fine slurry particles towards the inner wall. These particles spiral downward along the wall and are collected into the slag discharge system. The purified gas is then exported through

the extraction pipeline. This process achieves efficient three-phase separation and facilitates resource recovery.

4.2. Complete Workflow

The gas-water-slurry three-phase mixed medium generated during drilling undergoes buffer and flow stabilization treatment in the feed pipe before entering the separation tank in a homogenized flow state.

Upon entering the separation tank, the mixed medium receives secondary buffering via the upper-middle baffles. Under the dominant influence of gravity, the solid slurry settles to the bottom of the tank and is directionally discharged by a screw conveyor. The liquid phase in the middle section passes through a filter screen to remove suspended impurities and is discharged in a regulated manner through the coordinated action of the drainage pump and the filter screen. The gas phase, entrained with fine slurry particles, naturally rises and accumulates in the upper section of the tank. It is then drawn into a cyclone separator through a negative pressure extraction pipe.

Within the cyclone separator, the gas forms a high-speed rotational flow field. Under the action of centrifugal force, the fine slurry particles are flung towards the inner wall, descend in a spiral pattern along the wall, and are collected at the bottom slag discharge port. This process ultimately achieves the graded, high-efficiency separation of the gas, liquid, and solid phases.

5. Material Selection and Dimensional Requirements for the Device

In the design and research of gas drainage borehole anti-blowout devices, it is essential to determine the adapted operational parameters for each core component based on the complex geological conditions and specific operational environment of the underground coal mine. To ensure stable device performance under harsh working conditions—such as high humidity, high dust, strong corrosion, and instantaneous high-pressure impact—it is imperative to select highly compatible specialized materials according to the functional requirements of each component, and to precisely design the dimensions and structure of each part according to actual working conditions.

5.1. Anti-Blowout Sleeve

The inner diameter of the blowout preventer sleeve should be designed to be 2-5 mm larger than the drill pipe's outer diameter. For commonly used drill pipes with an inner diameter of $\Phi 73$ mm, the sleeve's inner diameter can be designed between $\Phi 75$ mm and $\Phi 78$ mm. This ensures the sealing components (rubber seals and brushes) fully cover the drill pipe surface and form an effective seal.

When the borehole diameter is $\Phi 140$ mm, the outer diameter can be designed between $\Phi 160$ mm and $\Phi 170$ mm to ensure the sleeve seals against the borehole connection and maintains structural integrity.

The length of the blowout preventer sleeve should typically cover the contact area between the drill pipe and borehole. Generally, the sleeve length is designed between 20-40 cm, with specific dimensions adjusted based on borehole depth and operational requirements.

The primary function of the blowout preventer sleeve is sealing and preventing gas leakage. Its body material must exhibit high corrosion resistance, high-temperature resistance,

pressure resistance, and wear resistance. Common materials include stainless steel alloys, composite metals, and high-wear-resistant alloys, which can operate stably for extended periods under high gas pressure and high-temperature conditions. Considering cost, performance, maintenance, and replacement frequency, stainless steel alloys offer high practicality as a material.

The external rubber hose of the blowout preventer sleeve utilizes EPDM rubber with excellent elasticity. Under the action of the thrust ring, it effectively expands to tightly seal against the coal seam wall and other contact surfaces while maintaining pressure resistance and high-temperature tolerance.

The inner brush bristles of the sleeve serve sealing and dust-blocking functions. High-strength, wear-resistant, and corrosion-resistant stainless steel wire bristles are selected. These maintain excellent sealing and cleaning performance over extended periods in high-temperature, high-pressure, humid, and highly corrosive environments.

5.2. Four-Way

To accommodate the varying flow and pressure requirements across multiple pipeline connections, the main body of the blowout preventer spool is constructed using $\Phi 140$ mm and $\Phi 219$ mm steel pipes. The material selected is stainless steel, known for its excellent corrosion resistance and high strength. The pipelines are connected via threaded rings to ensure secure and leak-proof joints.

5.3. Gas-Water-Slag Separation Tank

Underground mining conditions such as gas accumulation, enclosed dampness, coal body erosion, and instantaneous pressure impacts are particularly extreme. For core components of the gas-water-slurry separation tank assembly—including the main tank body, filtration elements, and inner walls of the cyclone separation barrel—targeted material selection and optimization design were conducted. This approach integrates their functional roles in sealing protection, separation purification, and wear resistance with long-term service requirements. By precisely matching the mechanical properties, corrosion resistance indicators, and underground compatibility characteristics of materials, the device ensures robust structural stability, operational safety, and long-term service durability in complex and harsh mining environments.

Main Housing:

Constructed from high-strength stainless steel welded components, leveraging its superior pressure resistance and corrosion resistance to withstand the corrosive effects of the mine's humid environment and the instantaneous pressure shocks generated by the spray nozzles. This prevents structural deformation of the housing, thereby avoiding the risk of gas leakage and ensuring the overall structural stability of the device during long-term operation.

Filter Components:

The filter mesh is crafted from composite porous materials with wear-resistant and high-temperature properties. It achieves precise and efficient retention of coal-rock waste particles across varying particle sizes. This significantly enhances the unit's anti-clogging performance and improves gas-water-slurry three-phase separation efficiency, extending the operational lifespan and stability of the filter components.

Cyclone Separator Inner Wall:

The inner wall of the cyclone separator is treated with an

anti-erosion coating. This effectively resists wear caused by high-speed erosion from fine coal and rock particles, reduces impurity residue during gas purification, and substantially improves the purity of extracted gas.

6. Conclusion

(1) The complete set of negative pressure efficient gas extraction and blowout prevention equipment is formed by integrating the orifice blowout prevention, dynamic gas-water-slag separation, discharge, and monitoring systems. The blowout prevention sleeve adopts a three-stage sealing structure, significantly enhancing sealing performance and safety.

(2) The design of the gas-water-slag separation tank achieves integrated dynamic separation. Through the dual separation processes of gravity sedimentation and cyclone separation, the separation of gas, liquid, and solid is made more thorough, thereby improving separation efficiency.

(3) Through reasonable material selection and dimensional design, the system is suitable for high-humidity, high-pressure, and highly corrosive underground environments.

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