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Experimentation on a new type of mining emergency rescue relay cabin

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ABSTRACT
This study designed an innovative mining emergency rescue relay cabin by comparison with existing hedging facilities with respect to function, service object, structure, size, and system components. The structures and systems of the emergency rescue relay cabin were designed and implemented. An air-tightness test indicated a test chamber relief rate of 26 Pa/min, which meets the requirements. Furthermore, an airsleeve air supply test indicated an air supply rate of 220 L/min, which is sufficient for the staff replacing the equipment in the emergency rescue relay cabin. The total air supply volume was 9680 L, which can be supplied via two bottles of 40 L, 15 MPa compressed air.
KEYWORDS: Emergency rescue relay cabin; relay cabin site selection; system and structure; tightness test; airsleeve air supply test

1. INTRODUCTION

The main hedging facilities of existing underground emergency systems include fixed refuge chambers and movable rescue capsules, both of which possess advantages such as being able to accommodate a considerable number of personnel, complete internal protection systems, and broad security protection ranges. However, several problems are currently hindering the application of refuge chambers and rescue capsules. Among these are long construction time, high usage, operation, and maintenance costs, and concentrated protection on the work surface in the mining area. To resolve these issues, this study investigated and designed a new type of mining emergency rescue relay cabin. Compared with existing underground hedging facilities, the new mining emergency rescue relay cabin has various advantages, such as small size, flexible usage, easy installation and transportation, diversity in protection objects, and low production cost (Li, 1989; Ni et al., 2013; Wang et al., 2010; Sun, 2011a). Combined with existing underground hedging facilities, this new type of emergency rescue relay cabin can achieve comprehensive coverage of the underground hedging space, not only lowering the cost of building underground emergency rescue systems, but also providing timely resources and equipment to underground hedging and rescue personnel, and both improving mine rescue efficiency and reducing casualties.

2. CHARACTERISTICS

2.1 Application feature comparison

The key feature of existing major hedging facilities, fixed refuge chambers, and movable rescue capsules is the internal life-support system—the main function of which is to provide a safe space for the hedging personnel waiting for rescue underground (Moncef et al., 1996). In contrast, the main function of the emergency rescue relay cabin is to provide materials and energy supply for the mine rescue personnel and hedging personnel so as to ensure the continuity of the rescue and hedging actions. Overall, the proposed relay cabin provides temporary protection for the rescue workers and hedging personnel.

2.2 Comparison of application objects

The application object of existing major hedging facilities, fixed refuge chambers, and movable rescue capsules is primarily the underground personnel (Gao et al., 2011; Jin et al., 2012; Sun, 2011b; Gao, 2011). In contrast, the emergency rescue relay cabin can not only serve for hedge personnel, but also provide mine rescue personnel with oxygen bottles, self-help equipment, food, water, communication devices, batteries, and other essential hedging and rescue energy supplies.

2.3 Structure and dimensions comparison

The average dimensions of a movable rescue capsule in existing hedging facilities are 23 m × 2.4 m × 2 m, which can accommodate 30 people. The internal structure is divided into transition area, living area and equipment area. The average dimensions of a refuge chamber for 30 people are 25 m × 4.5 m × 3.5 m. The internal structure is divided into refuge chambers on both sides and the hedging area in the middle. For the emergency rescue relay cabin to provide energy and

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supplies for 40 people, the overall cabin dimensions are only 1.52 m × 1.30 m × 1.77 m, as shown in Figure 1. The internal structure is divided into battery and power source area, supply storage area, equipment replacement area, and communication area, as shown in Figure 2.

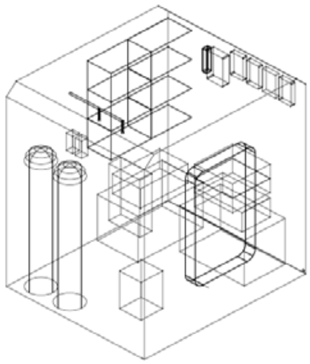

Figure 1: Internal structure of the emergency rescue relay cabin.

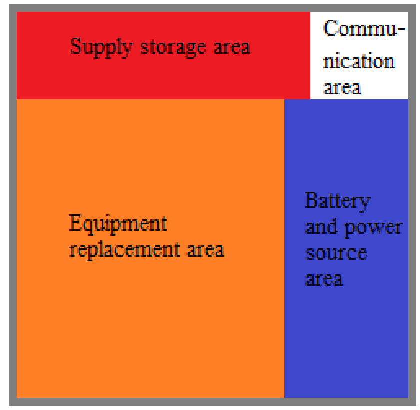

Figure 2: Functional compartments of the relay cabin.

The comparison shows that, for the same number of people, the emergency rescue relay cabin has a smaller size. Further, compared to the movable refuge chambers, it can move flexibly along pre-laid tracks by the roadway, allowing for rescue missions near and above the work surface, and others near and outside of the mining area along the roadway.

Table 1: Costs associated with hedging facilities.

Items	Relay cabin	Movable rescue capsule	Fixed refuge chamber
Material cost	263,000	2,000,000	3,000,000
Site Transfor - mation cost	300,000	1,500,000	4,000,000
Daily Maintenance fee /year	55,000	97,000	150,000
Total	618,000	3,597,000	7,150,000
Number of people	Ventilation and rest space for more than 40 people	Hedging for 30 people	Hedging for more than 30 people

2.4 Comparison of system components

The life-support system of existing major hedging facilities, fixed refuge chambers, and movable rescue capsules primarily includes the following: fire and explosion protection system, closed buffer system, air curtain isolation system, oxygen supply system, cooling and dehumidifying system, monitoring and control system, and communications systems (Sun, 2010). The main function of the emergency rescue relay cabin is to provide a temporary hedging place and supplies and energy for the rescuers and endangered workers. Therefore, its internal systems consist of a basic protection system, pressure air supply system, communication and lighting system, supply and distribution system, and power supply system.

2.5 Construction cost comparison

The cost of the emergency rescue relay cabin, which includes material cost, site transformation cost, and daily maintenance fee, as listed in Table 1, is far less than that of current hedging facilities.

3. SYSTEM COMPONENTS

3.1 Exterior structure of the relay cabin

According to the features of the emergency rescue relay cabin and the condition of the domestic underground transportation equipment and roadway sizes, the final shape of the emergency rescue relay cabin is designed to be rectangular, with specific dimensions of 152 cm × 130 cm × 177 cm. The interior dimensions of the cabin are 150 cm × 128 cm × 175 cm. The entire relay cabin is steel welded to ensure a certain degree of strength and weight, thereby preventing cabin body inclination as a result of shock waves from the side (Han et al., 2011). In addition, the compressive and tensile properties are good. The front of the relay cabin has an explosion-proof door and an emergency switch. Furthermore, necessary interfaces are set up to enable connection with the outside, such as the ventilation port connecting to external air supply devices, water supply port, power supply interface, communication interface, and air vent.

3.2 System components of the relay cabin

The interior of the relay cabin consists of five sub-systems: enclosed system, air supply system, resource system, power supply system, and lighting and communications system.

Enclosed system. The emergency rescue relay cabin has relatively low design requirements in terms of guaranteeing the survival of personnel, but it must provide protection. The entire cabin body comprises an enclosed system consisting of the steel shell structure and the explosion-proof door. The steel shell of the system body is built with steel welding technology. The front panel located in the tunnel and the explosion-proof door can withstand an impact of 0.3 MPa, and ordinary shock waves. In addition, the relay cabin has a certain degree of air-tightness to prevent infiltration of toxic gases. After the personnel enter the cabin, a positive pressure of +200 ±100 Pa with a relief rate less than 30 ±20 Pa/min is maintained, which is slightly less than that of refuge chambers and movable rescue capsules.

Airsleeve air supply system. This system is mainly used for personnel to replace supplies. The airsleeve can be used to cover the upper body to form positive pressure and prevent poisonous gases from entering. In addition, the personnel can temporarily hedge in the airsleeve. There are two oxygen supply systems for the airsleeve air supply system: compressed oxygen bottles and external oxygen supply. The overall air supply system comprises compressed air bottles, compressed air bottle connectors, external pressure air ports, pressure regulators, airway, pressure gauge, muffler, ventilation isolation bag, and oil-water separator (Zhao et al., 2003; Zhang et al., 2009). The cabin also has two airsleeves, although only one is used when the equipment is being replaced. In emergency situations, both can open to ensure the hedging of two people.

Resource system. The emergency rescue relay cabin can be filled with self-rescuer, water, food, and first aid supplies based on actual need. In this study, the number of emergency rescue personnel and the safety factor were set to 40 and 1.2, respectively.

Self-rescuer. The emergency rescue relay cabin has 50 chemical oxygen 45 self-rescuers (with a safety factor of 1.2) meeting the equipment replacement requirement of 40 people. The rescuers are placed on the window. A consistent model specification for each rescuer and field worker is maintained. The emergency rescue relay cabin can also be used as a complementary mine warehouse to assure routine replacement (Gao et al., 2012; Jin et al., 2012).

Water and food. The emergency rescue relay cabin should have enough water and food for two people to use for four days (with a safety factor of 1.5). The cabin should contain 30 L of pure water. Further, the port is connected to the external water supply, which provides a significant amount of potable water. Referring to the relevant standards, the emergency energy intake should be above 2000 KJ/day·per person; the shelf life should be no more than three years. Further, 3 kg of emergency food should be stored in the compartment to provide food for emergency hedging personnel.

First aid supplies. Essential rescue supplies should be stored in the relay cabin, such as explosion-proof flashlights and explosion-proof batteries, for rescue workers to replace the rescue equipment and, thereby, increase the scope and time of rescue. According to the actual situations, the cabin can also store toolboxes, first aid kits, medicines, and the equipment required in emergency situations.

Power supply system. In the emergency rescue relay cabin, equipment such as lighting and communication devices require electricity supply. The power storage has two explosion-proof power supplies (one is the backup power supply); battery life is monitored regularly to ensure its electrical storage capacity. At the same time, an external electrical connection port is setup to ensure external power supply.

The provided power supply needs to guarantee four consecutive days of electricity supply.

4. EXPERIMENT AND ANALYSIS

A relay cabin air-tightness test and airsleeve air supply test were conducted in accordance with the design requirements for a closed air supply system.

4.1 Relay cabin air-tightness test

This test determined the cabin air-tightness performance by varying the gas pressure in the cabin.

Method. A compressed air bottle was connected to the air ventilation port of the cabin, and pressure sensor testing devices connected in the cabin; the pre-drilled holes in the cabin body were sealed with leak-proof mud. The monitoring and control system were then turned on, the data parameters adjusted, and the door closed. This was followed by the opening of the air bottle valve and injection of air into the cabin at a uniform rate of 1.5 L/min. Throughout the process, the cabin pressure was monitored using pressure sensors. When the cabin pressure rose to 500 Pa, the CO_2

cylinders were switched off and the pressure recorded every 20 s until the pressure dropped by 100 Pa, that is, 400 Pa higher than the initial value. The test was repeated five times and the pressure relief rate calculated.

Conclusion. As shown in Figure 3, the pressure relief rate can be obtained using the equations

$$y = -0.4334x+500, \quad R^2 = 0.930 \quad (1)$$

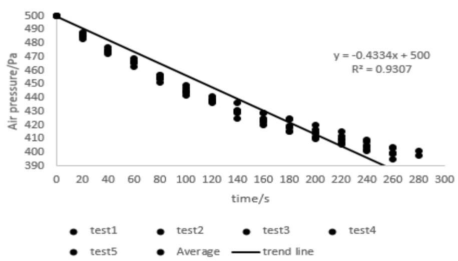

Figure 3: Pressure variation over time.

The pressure relief rate per minute calculated from the formula is 26 Pa, which meets the design requirements. The design models are therefore qualified and can be used as the carrier of the airsleeve air supply test.

4.2 Airsleeve air supply test

The airsleeve air supply test replaces poisonous gases with carbon dioxide, thereby determining the amount of compressed air needed to replace the equipment.

Method. The CO_2 cylinders, carbon dioxide detectors, sensors, cameras, and corresponding pipes were connected. The carbon dioxide detectors were placed in isolation airsleeves, simulating human head position, and the flowmeter inserted into the airsleeve. One camera was then focused on the meter reading, and another on the carbon dioxide detector readings. Finally, the cabin door was shut, the carbon dioxide cylinder valve opened, and carbon dioxide injected at a uniform rate through the backup port into the cabin. When the concentration of carbon dioxide in the airsleeve reached 2%, the carbon dioxide cylinder valves were adjusted to maintain the carbon dioxide concentration at 2%. The compressed air bottle was then connected to an external air vent, the gas-regulating flowmeter opened to a flow rate of 190 L/min, and the time, T1, recorded. Subsequently, the carbon dioxide concentration was recorded once every five seconds and, when the carbon dioxide concentration had fallen to 1%, the isolation airsleeve valve was closed and the test terminated. The above steps and test were again repeated with a flow rate of 220 L/min. Finally, the test data were exported to facilitate calculation of the wind pressure and enable the correct wind pressure rate to be chosen.

Conclusion. It can be concluded from Figures 4 and 5 that when the rate is 190 L/min, the time needed to reduce the carbon dioxide concentration to 1% is approximately 54 s. From the formula:

$$V = kStx \quad (2)$$

where: V is the amount of air required, k is the safety factor, S is the aeration rate, t is time, x is the number of people.

The required amount of air is 10260 L.

According to Figures 4 and 5, at an aeration rate of 220 L/min, the time needed to reduce the carbon dioxide concentration to 1% is approximately 44 s. According to the Formula 2, the required amount of air is 9680 L.

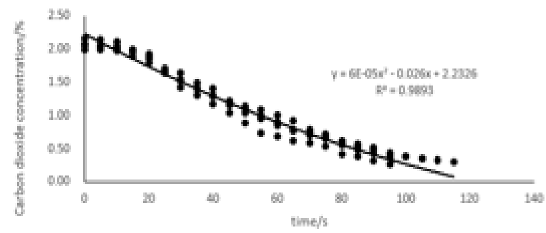

Figure 4 Carbon dioxide concentration-time curve for a rate of 190L/min.

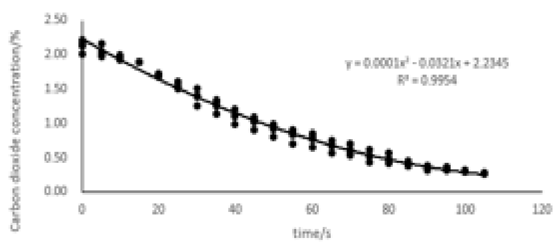

Figure 5 Carbon dioxide concentration-time curve for a rate of 220 L/min.

Because of the small amount of air required at the supply rate of 220 L/min, 220 L/min was selected as the final aeration rate, with two bottles of 40L compressed air used to meet the requirements.

5. CONCLUSIONS

The main difference between the mining emergency rescue relay cabin and existing hedging facilities are as follows: From the perspective of function the former focuses more on providing a safe environment for the rescuer and hedging personnel to replace equipment and supplement supplies, it can serve both rescue workers and hedging personnel, and the structure and dimensions are simpler and more flexible. In addition, it is more streamlined in terms of system components.

The exterior dimensions of the emergency rescue relay cabin are 152 cm × 130 cm × 177 cm. The cabin consists of five sub-systems: enclosed system, air supply system, resource system, power supply system, and lighting and communication system.

The pressure relief rate of the relay cabin was determined to be 26 Pa/min via a relay cabin air-tightness test. The result obtained meets the stipulated air-tightness requirements.

The air supply rate for the personnel to replace equipment in the emergency rescue relay cabin was determined to be 220 L/min via the airsleeve air supply test. The total air supply volume was 9680 L. This air supply volume requirement can be satisfied using two bottles of 40 L compressed air, which is in line with the relay cabin space-saving size requirements.

6. ACKNOWLEDGEMENT

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