

Drilling escape and rescue system in Wangjialing coal mine

Zhiling Huang^{*}, Longzhe Jin, Yuntong Ma, Hongmin Zhu

Civil & Environment Engineering School, University of Science and Technology Beijing, Beijing, China

ABSTRACT

Many problems are faced in the construction of emergency refuge systems, including the poor reliability of hedging facilities, the contradiction between hedge and escape, the high time consumption, high cost, and the big risk of drilling rescue technology. Shaft drilling escape and rescue systems are a combination of emergency refuge technology and drilling rescue technology. The key parameters of drilling escape and rescue systems are tested through man-loading and live sheep lifting experiments. Key parameters include no-supply guarantee time, response time, and human survival environment. This paper also examines the comfort and physiological parameters of experimenters and the influence drilling has over refuge chamber air supply systems.

KEYWORDS: mine shaft; emergency rescue; escape drill hole; emergency refuge; lifting experiment

1. INTRODUCTION

Ever since 33 miners were rescued from a 700m-deep shaft 69 days after a coal mine accident in Chile, countries with mining industries have paid great attention to the construction of underground hedging facilities. Continuous improvements in facilities and technology have been made. Although existing hedging facilities can provide trapped miners with hedge for some time after an accident happens, they cannot guarantee a successful rescue. There are limitations to the protective capabilities, and the contradiction between hedge and escape still exists.

Drilling rescue technology has recently become an emergency rescue method for coal mine accidents. It was adopted and resulted in success for the 2002 US Quebec Creek mine water penetration accident and the 2010 Chile coal mine accident. Ground and underground drilling, drainage, delivery of fresh air, and a liquid diet were adopted in the 2010 Shenhua Camel Mountain and Wangjialing mine water penetration accidents, with good effect. However, many of the current drilling rescue technologies can only be done after an accident occurs, and are time-consuming, high in cost, and risky. Most of the existing studies aim at problems like the accuracy of after-accident quick-hole and drilling.

This paper examines the combination of emergency refuge and drilling technologies to construct a shaft drilling escape and rescue system and realize miners' safe refuge and quick and efficient rescue. What's more, key parameters like no-supply guarantee time, response time, and human survival environment are studied through man-loading and live sheep lifting experiments.

2. CONSTRUCTION OF WANGJIALING DRILLING ESCAPE AND RESCUE SYSTEM

2.1 System Constitution

The drilling escape and rescue system is composed of the self rescuer, refuge chamber, supply drill hole, escape drill hole, vehicle mobile supply station, emergency rescue vehicle and emergency rescue capsule. It is closely connected to six systems and is not dependent on any existing systems. The refuge chamber is connected to five systems, and is therefore is facilitated with exclusive monitoring, compressed-air, and a water-supply system by the vehicle mobile supply station, as seen in Figure 1.

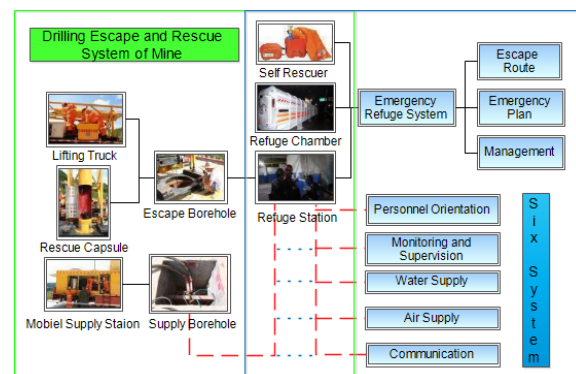


Figure 1: Composition of system.

The system is based on the refuge chamber. A $\phi 244.5$ mm supply drill hole is set up in chamber transition zone. Air-supply, water-supply, electricity-supply, and communication pipes are installed in the supply drill hole. A $\phi 790$ mm escape drill hole is set up in the survival zone. A vehicle mobile supply

^{*}Corresponding author – email : bkdhzl@163.com

station, emergency rescue vehicle, and rescue capsule are deployed on the ground.

The vehicle mobile supply station has many functions, including air-supply, electricity-supply, communication, and lighting. Its output interface is connected to the supply drill hole inner pipe. The emergency rescue vehicle is a unification of a winch, longmen frame, Jack, monitoring system, and operating board. It boasts a hoisting height of 500 m at maximum and a lifting speed of 1.5 m/s. The rescue capsule is a cylinder structure of 540 mm in diameter whose main material is Q345 steel. It boasts multiple functions like monitoring, communication, emergency oxygen supply, and emergency treatment.

2.2 System Operating Principle

In the case of a sudden accident underground, the staff should be evacuated from the wellhead using an established route to avoid the disaster area. The priority in case of a difficult situations should be evacuation to the refuge chamber, and entry into the rescue capsule should the need arise.

It is the ground command center's responsibility to organize rescue personnel from the wellhead to carry out rescue operations, as well as arranging personnel and rescue equipment to quickly drill the ground, in order to get the indoor refuge personnel from the chamber to the ground in time.

Under the premise of determining the environmental safety and the surrounding environment of the underground and the tunnel, rescue workers can be arranged from the borehole into the refuge chamber, improving the efficiency of the rescue.

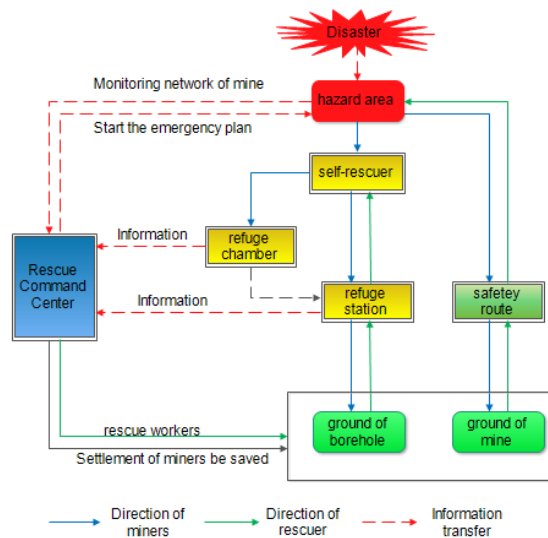


Figure 2: Emergency rescue process based on borehole rescue system.

3. HOLE RESCUE SYSTEM EXPERIMENT

3.1 General Situation of Refuge Chamber in Wangjialing Coal Mine

The Wangjialing refuge chamber is located in the 20106 working face of the outer auxiliary transport roadway between the machine and the big Lane. It has a rated service number of 100 people. The tunnel section has a 4 x 2.8m rectangular cross section. Both ends of the transition region are 9 m, and the living area is 36.5 m and space size is 410 m³.

3.2 Test Instrument

The chamber internal oxygen concentration, carbon dioxide concentration, temperature, and humidity are tested with CD7 type, which is seven in one multifunctional environment parameter sensor. The wind speed was measured by JFY-4 ventilation and multi parameter detectors. Noise was tested via a AWA6270 type noise analyzer. The blood pressure and the pulse produced from a laboratory test are used in the ABP-A091V type multifunctional electronic blood pressure meter.

3.3 Experiment Process

There were 100 experimental personnel in the laboratory. The escape drill used live sheep to enhance the simulation. The tests were carried out for 8 hours and divided into three stages:

1) 4 h no supply experiment - at this stage, there is no oxygen supply and carbon dioxide removal in the chamber. The escape hole and refuge chamber back to the outlet are closed.

2) 1 h oxygen supply experiment by drilling - in this stage, the ground supplies the wind by drilling, and air supply is set to 300 m³/h;

3) 3 h lift up living creatures test - in this stage, the experiments are carried out by using the escape drilling and ground lifting equipment.

4. ANALYSIS OF EXPERIMENTAL RESULTS

4.1 Analysis of Environmental Parameters in Refuge Station

The changes of oxygen concentration, carbon dioxide concentration and temperature-humidity in the refuge chamber during the experiment are shown in Figures 3 and 4.

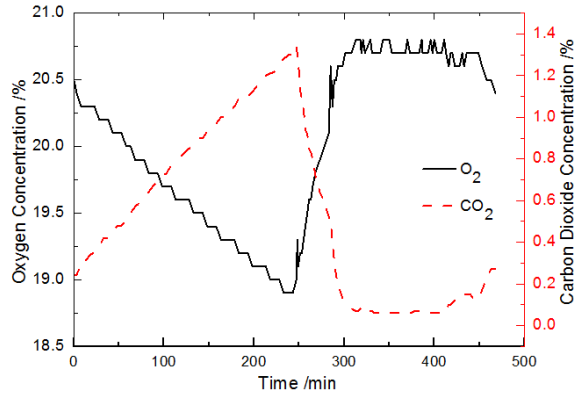


Figure 3: Change of oxygen and carbon dioxide concentration in refuge station during experiment.

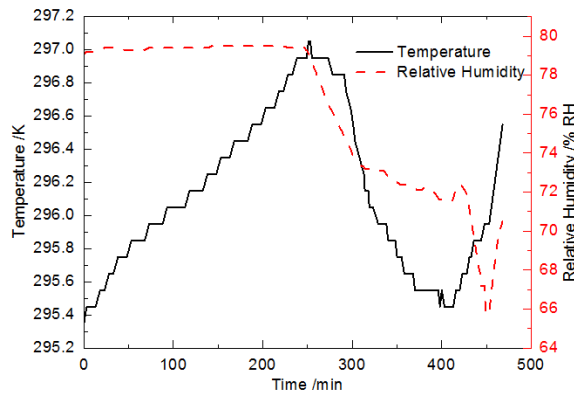


Figure 4: Change of temperature and humidity in refuge station containing experimenters.

By analyzing the changes of environmental parameters inside the refuge station, we can conclude that:

1) System support time without any supply is longer than 4h. In the first 4 hours of the experiment, 100 individuals exercised in an isolated refuge station with no supply. During this time, oxygen concentration in refuge station reduced from 20.6% to 18.7%, carbon dioxide concentration increased from 0.07% to 1.34%, and temperature rose from 295.45 K to 297.05 K. These parameters are within the safety range for human bodies.

2) An air supply volume of 0.05m³/min per person can satisfy survival needs. During the drilling and air supply process, which is the second stage of the experiment, when the volume of air supply is 300 m³/h (0.05 m³/min per person), oxygen concentration increases from 18.7% to 20.8%, carbon dioxide concentration reduces from 1.34% to 0.04%, and temperature decreases to 295.65 K in 60 min.

The results of noise measurement in the refuge station are shown in Figure 5. The height of the measure point from the floor of the refuge station is

1.3 m, which is also the ear height when experimenters are seated. From Figure 6 we can see that when air supply volume is 600 m³/h, the maximum noise intensity is 102.3 dB, and noise intensity is mainly in the range of 50-70 dB.

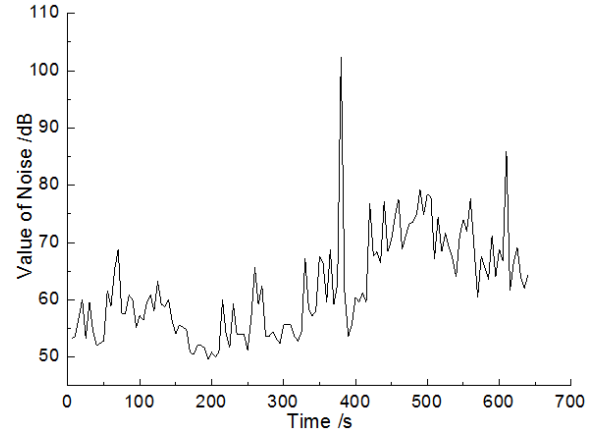


Figure 5: Environmental noise inside refuge station when air supply volume was 600 m³/h.

4.2 Analysis of Environmental Parameters Inside Rescue Capsule

The changes to the environmental parameters inside the rescue capsule during the lifting and falling process are shown in Figures 6 and 7, respectively. From Figure 6 we can conclude that during the lifting process, the concentration of oxygen and carbon dioxide inside the rescue capsule is similar to that of fresh air with less fluctuation, while the change of temperature is influenced by the temperature the of refuge station and ground of drilling.

Tests of noise in the rescue capsule (which is unloaded and loaded with sheep many times during the lifting and descending process indicate that noise intensity is mainly in the range of 45-70 dB, and the maximum value is no more than 115 dB, which is shown in Figure 8. The noise intensity in the rescue capsule with sheep is slightly less than that without sheep.

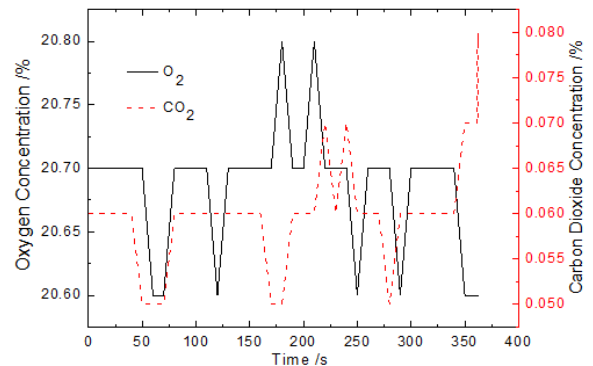


Figure 6: The change of temperature inside rescue capsule during lifting process.

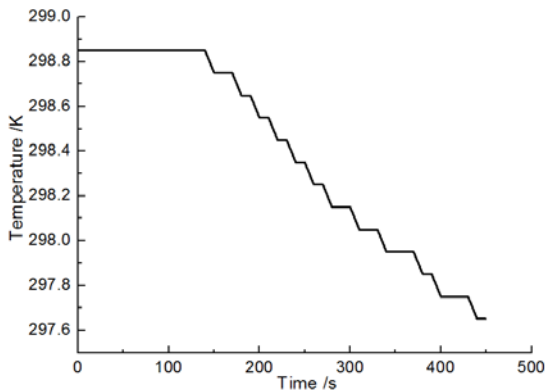


Figure 7: The change of temperature inside rescue capsule during falling process.

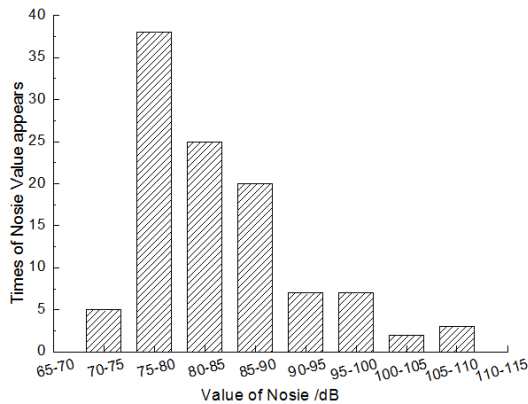


Figure 8: Noise intensity in rescue capsule when lifted.

4.3 Analysis of Experimenters' Comfort Levels and State of Sheep

Several questionnaires were conducted among 50 randomly selected experimenters 0.5 h, 3.5 h and 6.5 h after the beginning of the experiment. The questionnaires included questions probing the satisfaction with environmental comfort levels and status of individual physical conditions. Comfort

levels were then calculated according to questionnaires and the results are shown in Figure 10. In Figure 10, -2, -1, 0, 1, and 2 represent very uncomfortable, uncomfortable, average, comfortable, and very comfortable, respectively. From Figure 9 we can know that most individuals felt comfortable and satisfied with the survival environment of the refuge station. Even after the 4 h experiment without any supply, an uncomfortable reaction does not occur among individuals and few of them feel very uncomfortable.

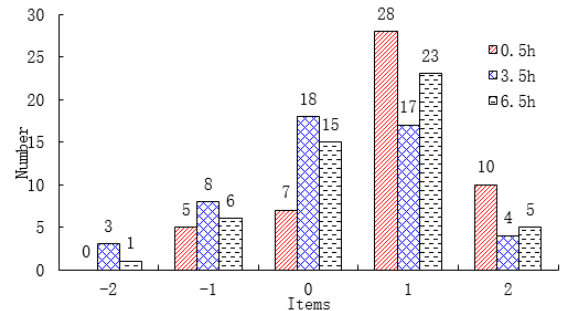


Figure 9: Comfort levels in experiment.

10 other individuals were randomly selected to have their blood pressure and pulse measured 0.5 h, 3.5 h and 6.5 h after the beginning of the experiment. The results are shown in Table 1. From Table 1 we can see that the blood pressure and pulse of experimenters showed no abnormal phenomena. During three measurements, the average value of blood pressure was 130.1/88.5 mmHg, and that of pulse was 71.3.

There were no abnormal phenomena for the sheep, except for two sheep crying and panicking due to fear after each sheep went through the lifting and falling process 4 times. Video monitoring systems showed that sheep behaved quietly with no obvious agitated activity.

Table 1. Results of blood pressure and pulse measurement.

Time	Blood Pressure/mmHg						Pulse/times per minute		
	Systolic Blood Pressure , SBP			Diastolic Blood Pressure , DBP					
	Min	Max	Avg±Std	Min	Max	Avg±Std	Min	Max	Avg±Std
0.5h	123	138	129.9±4.86	82	96	88.6±4.48	65	80	71.2±5.25
3.5h	125	135	130±2.98	84	94	88.1±3.03	67	81	71.9±4.61
6.5h	124	135	130.4±3.63	84	97	88.8±3.65	65	78	70.8±4.69
Average	130.1			88.5			71.3		

4.4 Tests of System Response Time

Response and preparing time of the emergency lifting truck were tested and the results are shown in Table 2. From the time workers inside the refuge station sent distress signals until the time that emergency lifting trucks and the mobile supply station arrived at the ground of drilling holes,

debugged the system, and prepared for rescue, the 121 min had elapsed. This is much less than survival time without any supply. Additionally, test results of hoisting speed indicate that it takes approximately 14min to lift one person, in which fall time makes up 7min and hoisting time makes up 6.3 min.

Table 2. Measurement of system response time.

NO.	Project	Time/min
1	Time consumed for mobile supply station to arrive	74
2	Time consumed to prepare for system	23
3	Time consumed to preheat diesel generating set and screw air compressor	13
4	Time consumed to set up gantry	11
5	Average one-way fall time of capsule	7
6	Average one-way lift time of capsule	6.3

4.5 Influence Borehole Has on Air Supply System

In order to study the borehole's influence on the air supply system, wind speed of the return air outlet and borehole were tested. The results are shown in Table 3. Negative wind speed indicates that wind flows from the refuge station to the ground of drilling.

As it is illustrated in Table 3, when return air outlet is open, escape drilling holes can work as air supply holes, with wind speed at 1.61 m/s. When return air outlets are closed and the compressed air supply is open, escape drilling holes can work as return air outlets, with wind speed at 0.25 m/s under the volume of 300 m³/h and at 0.56 m/s under the volume of 600 m³/h.

Table 3. Wind speed of borehole and return air outlet under different working conditions.

equipment condition		wind speed (m/s)			
Compressed air supply	air outlet	Bore-hole	Bore-hole	outlet1	outlet 2
None	Closed	Open	0.05	—	—
None	Open	Open	1.61	7.24	7.33
Volume of 300 m ³ /h	Open	Open	1.43	6.8	8.28
	Closed	Open	-0.25	—	—
Volume of 600 m ³ /h	Closed	Open	-0.56	—	—

5. CONCLUSIONS

From previous experiments and from summarizing the authors' analyses, the following conclusions are drawn.

(1) The proposed drilling escape and rescue systems consist of emergency refuge facilities, which includes a self-rescuer, refuge chamber, and refuge station, and drilling rescue facilities, which include a rescue capsule, emergency lifting truck, mobile supply station, and escape borehole. The process of emergency rescue based on the system was studied. The system can actualize safety and the high efficiency of escape and rescue in catastrophic conditions.

(2) According to experiments with individuals, the system support time with no supply was 4 h and time to debug and prepare the system was about 2 h. Individuals in the refuge station could get rescued with no supply outside.

(3) An air supply volume of 0.05 m³/h per person could satisfy survival needs for individuals in the refuge station. When air supply volume was 0.05 m³/min per person, oxygen concentration rose from 18.7% to 20.8%, and carbon dioxide concentration reduced from 1.34% to 0.04% in 60 min.

(4) Through the lifting experiment with sheep, environmental parameters inside the rescue capsule when it was lifted in the rescue borehole were measured. The reliability of animal lifting by a drilling escape and rescue system was verified.

6. ACKNOWLEDGEMENT

I would like to express my gratitude to all those who helped me during the writing of this thesis.

My deepest gratitude goes first and foremost to Professor Jin Longzhe, my supervisor, for his constant encouragement and guidance. He has walked me through all the stages of the writing of

this thesis. Without his consistent and illuminating instruction, this thesis could not have reached its present form.

Last my thanks would go to my beloved family for their loving considerations and great confidence in me all through these years. I also owe my sincere gratitude to my friends and my fellow classmates who gave me their help and time in listening to me and helping me work out my problems during the difficult course of the thesis.

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