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Study on New Emergency Refuge Chamber of Coalmine Underground

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Abstract: This study introduces the current situations of the research on the refuge chamber at home and abroad. Aiming at disasters prevented and environment for refuge chamber, it deals with the chamber's protection and positioning, notes for selection of chamber sites, reference sizes and requirements of strength and impermeability. Some designs for survival system in the refuge chamber are structured, including multistage oxygen supply, air cleaning system, temperature and humidity control system, dynamical system, monitoring and communication system, etc.

Keywords: Air cleaning, multistep oxygen supply, protection and positioning, structure design

INTRODUCTION

So many mining accidents, casualties and losses are quite severe problems that China should face all the time in mine safety control (Wang, 2006). Relevant data show that China's coal output makes up 35% of total world production currently, but death rate accounts for 80% of the global coalmines. According to statistics of causes of death in gas accident-the first killer to the coalmine safety, miners who die from explosion, shock wave or collapse caused by gas are preciously few, only accounting for 15-25% in China' coalmine gas and coal-dust explosion accidents (Cui, 2009). Most miners die from oxygen depletion, high-concentration poisonous and pernicious gases in nearby areas, or their no timely evacuation to safe areas because escape roads are blocked up by explosion (Zhou *et al*., 2002). If there are the confined spaces built in coalmine underground, the trapped miners can survive to great extent (Jin and Song, 2004).

Thus, the safe confined space can be applied for emergency refuge of the trapped people in dangerous environments in larger scope. By this way, it can guarantee life safety and gain enough relief time. This has become a new tendency for coalmine safety protection (Zhao and Wang, 2008).

The coalmining countries in Europe and America attach importance to emergency rescue for coalmine accidents. A lot of researches and experiments have been done on emergency chamber as an important part of emergency relief. They have accumulated rich experience in successful rescues.

Fig. 1: Arrangement of permanent refuge chamber

The emergency refuge chamber is the confined space set in dangerous working area of coalmine underground and is generally built by excavating laneroad wall. It is airtight and can withstand the impact of external forces to great extent. Oxygen supply system, carbon monoxide and carbon dioxide purification system, power supply system and communication system should be equipped inside of the chamber often. In addition, related monitoring and protection measures should be taken and enough food and water can be provided. At present, there are two types of emergency refuge chambers in main coal mining countries (Wang *et al*., 2010), Fig. 1 is Arrangement of permanent refuge chamber.

- Permanent refuge chamber
- Temporary refuge chamber

It is excavated in either side of a laneway or coal bed near mine working surface and supplied with oxygen to some extent for refuge chamber by such equipment as oxygen cylinder. After the getting ends on

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Table 1: Protective indexes

Protective index	Temporary refuge chamber	Permanent refuge chamber
• Type of casualty	Gas explosion, outbursts of coal and gas, fire, and roof fall	Gas explosion, outbursts of coal and gas, fire, roof fall, and flood
• Number of people protection	30~40	Over 50
P Protective time	≥prime time for rescue 72h	Continuing protection till rescue ending

- The refuge chamber can withstand instantaneous shock wave pressure (generally 1.5 MPa) from gas explosion; the chamber should be constructed with air-tight materials so as to ensure good airtight property and prevent poisonous and harmful gases' damages to body. The chamber should withstand high temperature at 1000 °C produced from gas explosion and coalmine fire
- Number of refugees in chamber should be decided generally speaking in consideration of affluence coefficient as well as laneway arrangement in mining area and distribution of operating personnel

Fig. 2: Arrangement of temporary refuge chamber

the site, the temporary refuge goes out of use. Meanwhile its equipments such as oxygen cylinders, communications and monitoring instruments can be removed to other newly-built temporary chambers. Figure 2 is layout of the US temporary refuge chamber.

Although the refuge chamber construction is involved in salient protective measures for coal (rock) and gas (carbon dioxide) in the Safety Regulations in Coal Mine, the specific requirements are simple relatively (Li *et al*., 2010a).

Some coalmines are constructed with refuge chambers in underground at home and these chambers are only equipped with compressed-air self-rescuers and air doors, whose airtight property and shock strength cannot satisfy requirements. Once gas explosion occurs, the mine pressure ventilation pipes are destroyed and rescue functions of the refuge chamber are ineffective. For this reason, the chamber doesn't give play its role of refuge in disasters (Li *et al*., 2012).

So, it`s essential to make a comprehensive research and design of the refuge chamber undermine, under the circumstance of the coal mine in China. This has important significant in keeping the coal miners` safety. Since 2006, with the support of the national 11th five-year plan to support science and technology project, a laboratory of simulation confined circumstance was built in University of Science and Technology Beijing and making the study of the related theory and environment control technical problems of the refuge chamber. Bring forward the key technology link of the refuge chamber and provide technical support for the life safety of coal miners undermine.

DESIGN OF EMERGENCY REFUGE CHAMBER

Protection positioning: Before design of refuge chamber, the positioning indexes of protective technology for refuge chamber should be determined at first based on data and casualty features of all types of mine accidents (Gao and Zhang, 2009). The technical indexes include protective, survival and physiological indexes as shown in Table 1 to 3.

Table 2: Survival indexes

Survival index	Allowed band
Carbon monoxide	≤0.0024%
Oxygen	18%~21%
Carbon dioxide	≤1%
Hydrogen sulfide	≤0.00066%
Temperature	≤35°C
RH	≤85%

Survival indexes should be decided by mine safety provisions

Table 3: Physiological indexes

• Physiological index	Parameter
• Moisture gain	61g per capita h
• Heat release	120W
CO_2 emissions	0.5~0.6L per capita min
Oxygen consumption ④	0.4~0.5 L per capita min

- Human's physiological indexes are diverse in different states. The slight movement in question is selected as parameter in consideration of quietly-sitting states for refugees
- The moisture gain is 61g/h for a man's sitting quietly in chamber at 25°C
- Heat value each man: 0.09-0.12kW in quiet state;0.2kW in slight physical labor; 0.275kW in medium physical labor; and 0.47kW in heavy physical labor
- Oxygen consumption decided in the Military Standards (GJB 401122000): 0.0149m^3 per capita hour in sleeping; 0.0264 m^3 per capita h in slight movement; 0.0495m^3 per capita h in medium movement

- Protective indexes
- Survival indexes
- Physiological indexes

Site selection principle: The following factors should be considered for refuge chamber: mine laneway layout; type of disasters; distance between miners' work place and refuge chamber; underground distribution of miners; supporting facilities (compressed air, power and water supply of systems) outside of refuge chamber; geologic structure, etc.

The temporary refuge chambers should be constructed near the getting sites with a capacity of 30-40 refugees, which is decided by number of miners on the getting site. The refuge chamber is not set in the return air course where there is a great deal of gas gathering. Moreover, the chambers should be far away from all various geological structure areas such as fault, crushed zones of faults and they should not be affected by earthquake. The position for chambers should be selected as coal bed or rock strata with sound strength and built with sufficient non-flammable protection layer. The refuge chamber should not be constructed in the places where there is underground water logging in case of inundation. Furthermore, they should be built near substation and powder magazine in case of fire disaster. According to overseas empirical data, the maximum distance from miners to refuge spaces should not exceed 1000 m.

Structure design:

- **Size of chamber:** Number of refugees and size of equipment in chamber as well as requirements of geological structure on support conditions should be considered fully for the size of chamber. There are some corresponding strict requirements for area and volume per capita in South Africa and US.

It is provided in South Africa's Directive B5 that the usable floor area per capita is 0.6 m^2 in refuge chamber, which falls into the range between 1.0 and 1.5 m^2 in the Workplace Practices. It is stipulated in the Refuge Alternatives for Underground Coal Mines Final Rule that the escape capsule should provide an area of 1.4 m^2 and a space of 1.7 m^3 at least.

In consider of replacement of gas and refuge comfort, it is suggested that usable floor area per capita is greater than and equal to 0.5 m^2 and the volume per capita greater than and equal to 1 m^3.

- **Design of chamber section:** Properties of surrounding rock, size and orientation of mine pressure acting on the chamber, service life, support ways and tunneling method for chamber, all should mainly be considered in a selection of chamber's sectional form. For the permanent refuge chamber, some factors such as supporting stability should be considered and round arch structure is recommended. For the temporary chamber, the trapezoidal frame should be adopted because of its space use ratio. The size of section should be decided based on size of facilities in chamber, miners held in chamber, geological conditions, supporting materials and structural form. In order to reduce cost, not only should the section be economic, but also the sum of costs for tunneling, supporting and later maintenance should be minimized.

- **Overall strength and air-tightness:**
  Overall strength: Aiming at influence of mine pressure and surrounding working face mining, appropriate support pattern should be used for chamber to satisfy deformation of the chamber.

The chamber's anti-explosion airtight door and wall mainly can withstand gas-explosion shock wave. Thus, they are designed according to strength of shock wave:

$$\Delta P_{\lambda} = \frac{0.196\text{r}}{r+1}(M^2 - 1) \tag{1}$$

where,
r = Air specific heat ration, assumed as 1.4
M = Ratio of shock wave speed and sound speed in medium

According to transmission of explosion shock wave, the chamber should be constructed at the side direction of shock wave. The pressure should reduce to 0.2 MPa below quickly in consider of shock wave behind explosion source of 300 m. In addition, based on laneway test results of gas explosion about mining escape capsule in Chongqing Coal Research Institute, the shock wave pressure for the refuge should be set as 1.5 PMa.

The anti-explosion wall should be required the reinforced concrete structure at over one meter thick referring to overseas standards and surrounding slotting should be over one meter deep for requirement of anti-explosion wall construction, so as to ensure connection strength of wall and rock mass. Crush resistance and shear strength should be checked for the wall design:

$$B = \frac{\sqrt{(\text{a}+b)^2 + 4Pab/f_c} - (a+b)}{4\tan\alpha} \tag{2}$$

where,
B = Thickness of airtight wall, m
a = Net width of chamber for airtight wall, m
b = Net height of chamber for airtight wall, m
P = Design pressure of airtight wall, MPa
f_c = Design value of concrete crushing strength, MPa
α =Included angle between the side of wedge-shape airtight wall and centre line of the chamber:

$$B \geq \frac{Pab}{2(\text{a}+\text{b})f_v} \tag{3}$$

where,
f_v = Shear strength for concrete design, MPa。

Air-tightness: In order to isolate outdoor poisonous and pernicious gas and prevent gas in occurrence of coal seam from entering chamber, the refuge chamber should be airtight. For air-tightness, the chamber indoor should be coated with airtight materials (Jin *et al*., 1998) and the chamber wall should be constructed with airtight cement as well as double door structure (one is anti-explosion door, the other is airtight door). The double door should be best airtight and set with air curtain (Liao and Su, 1998).

At present, a refuge chamber is required an internal and external pressure difference between 200 and 1000Pa. It is provided in the US Refuge Alternatives for Underground Coal Mines Final Rule that pressure in the escape capsule is 0.18 psi higher than that of the mine, i.e., 1241Pa.

Table 4: Comparison of oxygen supply methods

Oxygen supply ways	Effective oxygen content	Cost	Oxygen rate	Duration	Usage
Gas cylinder oxygen supply	100% pure oxygen	General	Controlled	Fixed storage and time	Oxygen source for temporary refuge chamber
Chemical reaction oxygen supply	45% oxygen content	Higher	Uncontrolled	Fixed storage and time	Spare oxygen source
Underground compressed air oxygen supply	21% oxygen content	General	Controlled	Continuous oxygen supply as long as pressure ventilation pipe is not broken	Oxygen source for temporary chamber
Ground drill-hole oxygen supply	21% oxygen content	Highest	Controlled	Continuing oxygen supply till rescue ends	Oxygen source for permanent chamber

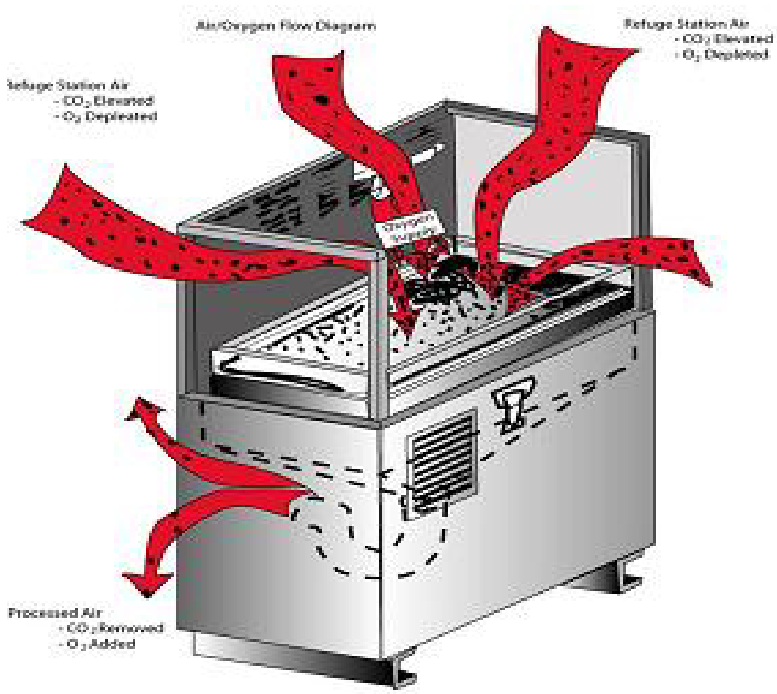

Fig. 3: Refuge one purifie

- **Survival system research:**
  Oxygen supply system: The oxygen supply ways for refuge chamber mainly includes: gas cylinder oxygen supply, chemical reaction oxygen supply, ground drill-hole oxygen supply and underground compressed air oxygen supply (Li *et al*., 2010b). Their advantages and disadvantages are shown in Table 4.

The permanent refuge chamber holds more people with large space. So diffuse-type oxygen supply is recommended; the temporary refuge chamber holds fewer people and its tightness is less than the permanent one, so distributive oxygen supply is recommended.

- **Air purification system:**
  Carbon dioxide removing technology: Some factors such as size of chamber, reaction efficiency and drug storage should be considered comprehensively in a selection of carbon dioxide as absorbent.

  - **Super (hyper) oxide absorptive method:** Oxygen will be released when super (hyper) oxide absorbs carbon dioxide and generally the super (hyper) oxide can be used as spare oxygen source. Its advantage is that it can release oxygen at the time of absorption of carbon dioxide. But the method is expensive with excessive heat in reaction.
  - **Soda-lime absorption method:** The soda lime is made up of 82% calcium hydroxide, 3% sodium hydroxide and 15% water and can remove acid gases such as hydrogen sulfide and carbon dioxide.

Advantages: low requirements for reaction condition, low price, reliable property and long quality guarantee period. Disadvantages: lower static absorption efficiency of soda lime and soda lime per kilogram can absorb 0.39 kg carbon dioxide. Air flow speed in the airtight space should be improved by the fan to raise absorption rate. Figure 3 is Refuge One Purifie.

- **Lithium hydrate absorption method:** Anhydrous lithium hydrate is white powder and it can generate lithium carbonate after absorbing carbon dioxide.

Advantages: With a high absorption rate, lithium hydrate per kg can absorb 0.8 kg carbon dioxide; passive absorption is available by hanging lithium hydrate

Fig. 4: Absorption curtain used for carbon dioxide

absorbing curtain as shown in Fig. 4. Disadvantages: expensive in price and excessive heat in reaction process. To sum up above absorbents, we should give preference to soda lime as a carbon dioxide absorbent while the super (hyper) oxide and anhydrous lithium hydrate as a spare absorbent when the chamber is equipped with power source and refrigeration equipment.

Carbon monoxide removing technology: Carbon monoxide is mainly removed by catalytic reaction of Hopcalite or noble metal catalyst. The non-metal catalyst-Hopcalite is selected as CO catalyst based on cost. Because carrying CO into the chamber by refugees is inevitable, CO is removed at the time of absorption of carbon dioxide by blending catalyst into CO_2 absorption bed.

Foul gas removing technology: There are more than 400 body metabolites including enzyme, mass of protein, fat metabolites and ammonia, which are unable to be diluted in the airtight space, so that it is terrible in the chamber and severely does harm to miners' health. In order for refugees to wait for rescuers coming smoothly, the foul gas should be removed. The activated carbon is most commonly used for absorption of foul gas because of its porous structure. The granular activated carbon is mixed into the CO_2 absorption bed. It can remove foul gas in air at the same time of absorption of carbon dioxide.

- **Monitoring and communication system:** The monitoring for a refuge chamber can be performed indoors and outdoors, mainly monitoring indoor and outdoor parameters in chamber. It is to measure concentration of carbon monoxide, carbon dioxide, oxygen, methane and hydrogen sulfide as well as temperature and RH in chamber indoors. In chamber outside, the concentration of carbon monoxide, methane, oxygen and smoke should be monitored. All monitoring data can be available by combining the sensor with existing mine monitoring systems and transmitted directly to the ground monitoring room by substation.

When mine disaster happens, the mine rescue command center can work out a rescue scheme if understanding refugees' situations in refuge chamber timely, so as to improve possibility of rescue for refugees greatly. In the chamber, three-level communication system can be set: wire anti-explosion phone, wireless phone (PHS) and sound-amplifying phone.

- **Power supply system:** In order to ensure indoor refugees surviving, the chamber should be equipped with current consuming apparatus, air cleaning facility, refrigeration equipment, etc. It is of extreme influence on rescue of the refuge chamber to provide electricity for current consuming apparatuses in chamber and maintain their operation.

The power supply system in refuge chamber can be divided into two parts: mine power and storing battery. The existing mine power may be supplied to the chamber by power cables because of maintenance at ordinary times and existing mine power cables not destroyed by disaster. When the mine power is suspended in disaster, the spare power storing battery should be started in order to maintain operation. In addition, the self-power generating device in chamber including two types: hand generator and pedal generator, are used in the event of ineffective spare powder supply.

- **Temperature and humidity control system:**
  Dehumidification technology: Because of moisture from human breathing, perspiring and carbon dioxide absorbing reaction, humidity in refuge chamber can becomes higher gradually. But high humid environment can make human uncomfortable, so that some symptoms such as sunstroke can occur easily, even endanger miners' lives. So the humidity of the chamber should be well handled. Commonly used dehumidification technology for the chamber includes refrigerating and solid dehumidification. The two modes can be used in the event of ineffective underground compressed air system and ground drill-hole compressed air system. When compressed air is normal, the humidity is controlled by air replacement.

Temperature control technology: In the airtight space, it is difficult to keep body heat balancing because of the limited space and no convection to the outside. Once the body heat exceeds the limitation that the body stands, the body temperature will go up. Dizziness, ringing in the ears, nausea and syncope occur with increase of body temperature. When body temperature goes up 39°C, miners' lives would be in danger.

Temperature control for the airtight space can be divided into two types.

Table 5: Comparison of refrigeration

Cooling mode	Advantage	Disadvantage
Vapor compression refrigeration	Refrigerant recycling use	Heavy power consumption, strong noise, serious pollution, unused in off-position
Ice storage refrigeration	Use in off-position	Heavy power consumption for ice storage at ordinary times; large volume of ice storage
Solid sublimating refrigeration	Saving space and Use in off-position	Large initial investment, dry ice storing for potential safety hazard

- **Cooling by ventilation:** When mine compressed air or ground drillhole compressed air is in gear, the air in the chamber can be replaced in the action of pressure field, so as to reach fresh oxygen supply, balancing temperature and humidity and poisonous and pernicious gas removing. Moreover, as no thermal-protective coating is set in the camber, so the heat can be conducted and dispersed through coal layer
- **Refrigeration equipment cooling:** Vapor compression refrigeration system: Refrigerant recycles once through evaporation, compression, condensation and throttling in the system

Ice storage refrigeration: Store the refrigeration capacity needed by air conditioner into ice at ordinary times. Once disaster occurs, the refrigeration capacity can be used.

Solid sublimating refrigeration: Refrigeration is available by larger latent heat of vaporization and lower vaporization temperature in ice sublimating.

Their advantages and disadvantages are shown in Table 5.

- **Subsystem:** A, Drinking water and food Body heat per day = weight(kg)×(22-33) and consuming one kilo-calorie per day according to US RDA standard and needing one mL of water.

In order to satisfy living needs of a refugee, a man should need 2000 kilo-calories per day and 2 L of drinking water. In order to save the storing volume, the food is made by military compressed cereal bars. Food ration is calculated by calories of allocated food.

Quantity of food and drinking water in temporary refuge chamber should be stored by seating capacity and refuge time. Food and drinking water can be provided by pipe and stored in appropriate quantity for permanent refuge chamber.

Emergency miner's lamp: Providing a secure and bright environment for miners once the mine power system outage.

Notice board: Introducing inner equipment arrangement, operating instructions and counter measures in emergency.

Tool kit: There are commonly-used tools for maintenance of equipment, including flathead/Philips screwdrivers, wrench, pliers and knife.

First-aid case: Including common articles dealing with injuries such as emergency manual instruction, tourniquet, splint, bandage, band-aid, absorbent cotton, iodophor cotton stick, thermometer, etc.

CONCLUSION

In order to maintain mine operating personnel's life safety and health and safeguard coal mine safety in production, it is very urgent and necessary to carry out six systems of underground safety self-rescue, namely, perfect monitoring, personnel positioning, emergency hedging, compressed air self rescue, water supply for rescue and signal communication.

The refuge chamber is an important step of the six systems for safe refuge and it is used to provide survival space for life safety for trapped miners in the event of the underground emergency disasters and is also a last life safeguard for the underground operating personnel.

The refuge chambers constitute a whole system of the underground mine emergency refuge system in combination with mine monitoring, personnel positioning, compressed air self-rescue, water supply for rescue and signal communication system. The system promotes the coal mine safety control in all-round way, ensure life safety of miners and gain the time for the ground rescue.

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