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Relative Humidity Control of Coalmine Underground Refuge Confined Space

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Abstract

Air humidity is an important index of the human living environment. It is found through the manned test that environment humidity goes up significantly in the underground confined refuge space during mine disasters. The RH control in environment becomes important research task in the research on life safeguard in the underground refuge confined space. The tests were done for four commonly-used dehumidizers in the ground simulated laboratory established by the theoretical analysis on humid load of the mine refuge chamber. The results show the mineral drying agent is the best dehumidizer applied for the refuge chamber. Test results are proved through calculation in theory, and we get use level and replacement cycle of dehumidizers in the refuge chamber. This will provide a theoretical basis for humidity control in the underground confined space.

Keywords: Confined space, Refuge chamber, Humidity control, Manned test, Simulation test.

1. Introduction

But how to design an ISMR efficiently and scientifically is a challenging work. After all, the robot is classical information system and complex system, so its core problem is the system modeling. So far, there are still no unified modeling methods for it because of the complexity of applications. The lack of integrated methods of modeling leads robotic developers to analysis and design systematically so hard.

During mine disasters, the refuge chamber is the space on which refugees rely. It is the key point in the emergency rescue system and important tasks in the mine emergency refuge research to guarantee miners' life and health and gain time for rescue. The relative humidity (RH) is an important parameter for environment control in the refuge confined space. It is reported through research that RH has an important influence on human body [1], i.e. its high-low degrees affect all physiological functions of human body. It is found through related data from refuge chamber manned tests the RH goes up quickly and the body comfort level goes down promptly in the underground crowd refuge confined space [2]. How to effectively control environment humidity in the confined space becomes an urgent issue of the underground emergency refuge research [3].

2. Refuge Chamber Manned Test

In order to establish theories related to the technology of large space environment control and crowd life safeguard, and verify stability and reliability of supporting systems and explore changes of environmental parameters in the underground refuge chamber, the 48-hour manned test for 100 miners was done in the Mining Area I6 of Datun Kong Village Coalmine of Jiangsu in China on February 16,

2012. The test was divided into three stages: chemical oxygen supply, compressed oxygen supply test and compressed-air oxygen supply. In the compressed-oxygen supply test, the underground sudden disaster was thoroughly simulated for the refugees' survival test in confined space without external supply as shown in Fig. 1. The compressed oxygen supply test was performed for 12 hours with 80 miners and 20 testers and operators. In the test process, the working conditions in the refuge chamber were simulated during underground disaster, and the tested personnel maintained the lowest activity level. The refuge chamber was equipped with three mining 7-in-1 multifunctional parameter testers, four portable mining multifunctional parameter testers and several hygrometers & thermometers. The selected environment testing points were located in the miner-intensive area, recording data once every ten minutes. The temperature changes in the test process are shown in Fig. 2 and Fig. 3.

Fig. 1. Manned test of refuge chamber in the Mining Area I6 of Kong Village Coalmine

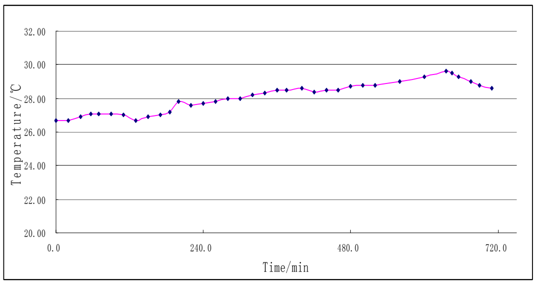

Fig. 2. Temperature change curve in 12 hours

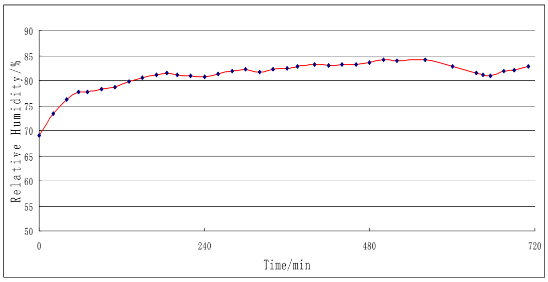

Fig. 3. Humidity change curve in 12 hours

The compressed oxygen supply test was done from 26.7℃ to 29.2℃ slowly, and humidity from 69.1% to 82%, then fluctuating at the range of 81% and 84.1%. It is seen from the manned test and related comfort level that inner temperature in the refuge confined space changed within the controlled scope during coalmine disaster. But the significant increment of humidity exceeded the normal comfortable humidity. Thus, the humidity control was studied based on the underground emergency confined space.

3. Theoretial Analysis on Humidity Load in Refuge Chamber

Humidity load refers to total moisture gain diffused from humid source in the confined space to the indoor [4]. The surrounding rock in underground refuge chamber could let out moisture to the space at several hundred meters deep. Thus, the chamber had its own characteristics compared with the ground buildings. It is an important basis for the research of chamber environment control correctly to analyze and calculate moisture gains of humid sources in the chamber.

In the entirely airtight situation during rescue, the humid sources in the chamber include: moisture from surrounding rock to the inner chamber [5], moisture from body and equipment. Man-made moisture in the chamber is ignored [6]. So, total moisture load (W) in the confined space of the refuge chamber is expressed in the following formula:

$$W = W_1 + W_2 + W_3 \tag{1}$$

Where, W_1:Moisture gain from surrounding rock, kg/s

W_2:Moisture gain from equipment，kg/s

W_3:Moisture gain from body，kg/s

Moisture gain from surrounding rock[7-9]**:** In refuge chamber, its wall face is connected with rock and coal bed, and underground water in surrounding rock or coal bed can seep into the chamber inside through porous structure on the chamber wall. As a result, the air humidity in the chamber increases. So this part of moisture gain should be considered. As the factors influencing the wall moisture gain are very complex, there is no wished wall moisture gain formula at present. Without actually-measured data, the moisture gain from surrounding rock goes by the chamber wall moisture gain.

$$W_1 = A_b g_b \tag{2}$$

Where, A_b: Newly-built internal surface area, m^2

g_b: Moisture gain of internal surface area per unit, $g/(m^2h)$;For general newly-built concrete adherence, g_b=1-2$g/(m^2h)$;For general newly-built concrete adherence, g_b=0.5$g/(m^2h)$

Moisture gain from equipment: The refuge chamber is equipped with such as moisture-transferring equipment as ice-stored air conditioner and oxygenating purifier, and there are free surfaces of pool, water stored for sanitary installations and ground ponding in the chamber. They are important constituents of moisture sources in the refuge chamber because they transfer moisture to the air constantly.

Their moisture gain goes by the following formula:

$$W_2 = A_W(\alpha_W + 0.00363v)(p_{WV} - p_{aV})\frac{B_0}{B} \times 10^{-5} \tag{3}$$

Where,W_2: Moisture gain from equipment, *kg/s*

A_W: Total surface area for moisture vapor, m^2

a_w: Evaporation coefficient in different water temperature, *kg/(NS)*

v: Air flow velocity on vapor surface, generally assumed as 0.3*m/s*

P_{WV}: Partial pressure of saturation water vapor corresponding to water surface temperature, *pa*

p_{aV}: Water vapor partial pressure in air, *pa*

B: Actual barometric pressure, *pa*

B_0: Standard atmospheric pressure, *pa*

Moisture gain from body: In order for convenient calculation, the base number by adult men multiplied by the coefficient of personnel proportion is called clustering coefficient. So, the body moisture gain can be calculated by the number of adult men in the chamber amortized the clustering coefficient, and the body moisture ga in can go by the following formula:

$$W_3 = 0.278 n \beta g \times 10^{-6} \tag{4}$$

Where, W_3: Body moisture gain, kg/s

n: Number of all personnel in the space

β: Clustering coefficient, and assumed as 0.9 for refuge chamber

g: Hour moisture gain for adult man, g/h

The dehumidification way and related dehumidizers are studied experimentally after total humid load in the confined space of coalmine refuge chamber is determined.

4. Simulated Test Of Refuge Chamber Dehumidification

One of the key drying agent dehumidification techniques is to select drying agent with good hygroscopic property. That is to say, the drying agent can absorb a great deal of water with a rapid dehumidification rate, and keep humidity stable in a short time. The refuge chamber should be big in space without external power support and good airtight and heat-insulating properties. So, these properties should be considered in the selection of air dehumidification techniques and dehumidizers in the refuge chamber.

Establishment of test platform: Aiming at studies on dehumidizers and their application for the chamber in the paper, the humidity balance of environment for around 100 refugees should be guaranteed in the confined space. However, due to large space in the chamber and limited test conditions, the test was hard to perform. For this reason, the underground refuge chamber environment was simulated at the constant temperature and humidity lab on the ground for the test as shown in Fig. 4. The lab interior is 8100mm long, 3700mm wide and 3500mm high, equipped with a directly-vaporing independent constant temperature and humidity system, which could satisfy requirements of constant temperature and humidity accuracy in the chamber.

The lab was equipped with the following instruments: CZC5 portable multi-parameter measuring apparatus which could be used to measure atmospheric pressure, absolute pressure, differential pressure, wind speed, etc.; DSR-TH temperature-humidity recorder which was used to measure temperature and humidity in the chamber; US Rayteck ST60 infrared thermometer which was used to measure temperature of wall face; electronic balance which was used to measure drying agent mass changes.

Fig. 4 Test platform in constant temperature

Determination of dehumidification ways and selection of test dehumidizers: The common dehumidification techniques include head pump dehumidifying, refrigeration dehumidifying, solid dehumidifying, liquid dehumidifying and film dehumidifying. All dehumidification techniques can be shown in Table 1.

Table 1 Comparison of properties of air dehumidifying method

Operational approach	Dehumidification by cooling method	Dehumidification by liquid absorption method	Dehumidification by solid absorption method	Dehumidification by turning wheel	Dehumidification by film method
Separation principle	Condensate	Absorbing	Adsorbing	adsorbing	Permeating
Dew point after dehumidification/℃	0~-20	0~-30	-30~-50	-30~-50	-20~-40
Floor area for equipment	Medium	Large	Large	Small	Small
Operating maintenance	Medium	Difficult	Medium	Difficult	Medium
Disposing air amount/ (m3/min)	0~30	100~2000	0~2000	0~200	0~100
Scale of production	Small to large	Large	Medium to large	Small to large	Small to large
Main equipment	Refrigerator surface cooler	Absorption tower, heat exchanger and pump	Adsorption tower, heat exchanger and changeover valve	Turning wheel dehumidifier, heat exchanger	Film separator and heat exchanger
Energy dissipation	Big	Big	Big	Big	Small

The moisture in the refuge chamber is mainly from breathing, body surface, equipment and environment control. In consideration of actual conditions in the chamber, the solid adsorption dehumidifying technique is used for dehumidification generally, that is, the dehumidizer is mainly used. According to special use for the refuge chamber, activated carbon drying agent, silica gel, mineral drier and NCZ-1 agent are selected as dehumidizers for the test as shown in Fig. 5-8.

Fig. 5 Activated carbon drying agent

Fig. 6 Silica drying agent

Fig. 7 Mineral drying agent

Fig. 8 NCZ-1 agent

Lab static field test: At first, a 12-hour static field test should be done for the confined space, and such parameters as environment change can be measured. In the test, changes of parameters in the constant temperature and humidity lab are shown in Fig. 9.

During the 12-hour static field test as shown in Fig. 9, humidity is nearly not any changing, keeping

RH at 95%, and other parameters are not any changing basically in the constant temperature and humidity lab. Thus, the parameters in test external space environment have no affect on test results.

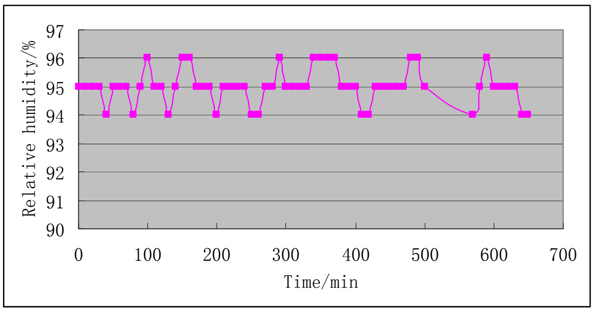

Fig. 9 Humidity changing curve with time in constant temperature and humidity lab

Test process and result analysis: Take the dehumidizers which are dried off, each is stacked in a volume of 2000cm^3; then, weigh it and write down as follows:

Table 2 Weight before test for 2000cm^3 dehumidizers

	Activated carbon drying agent	Silica gel drying agent	Mineral drying agent	NCZ-1 agent
Tray weight/kg	1.095	1.110	1.155	1.155
Total weight/kg	3.210	2.095	3.445	2.885
Net weight/kg	2.115	0.985	2.290	1.730

The stacking density for four dehumidizers is as follows:

Table 3 Stacking density for four dehumidizers

	Activated carbon drying agent	Silica gel drying agent	Mineral drying agent	NCZ-1 agent
Stacking density/g·cm-3	1.0578	0.493	1.145	0.865

Lay four dehumidizers on the 450×350mm ceramic trays respectively, with even distribution. Put the trays on the test table by equal distance evenly in the constant temperature and humidity lab, with uniform test environment as shown as follows:

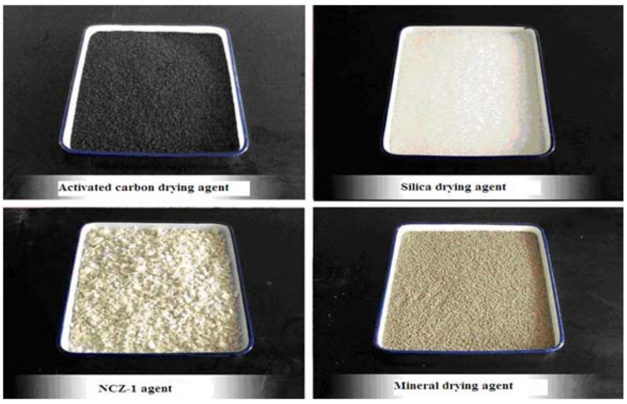

Fig. 10 Initial state of four dehumidizers on the trays

a. Weight changes in the hygroscopic process of dehumidizer

Record changes of weight for four dehumidizers with time, and get to know the water amount adsorbed by dehumidizers; then draw the weight-time chart in the moisture-removed process for different dehumidizers, so as to perform the further analysis. The weight for four dehumidizers changes with time as shown in Fig. 11.

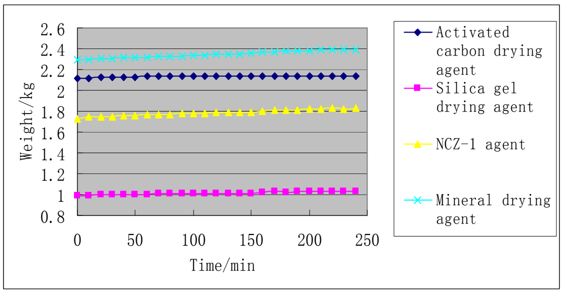

Fig. 11 Changing curve of drying agent weight with time

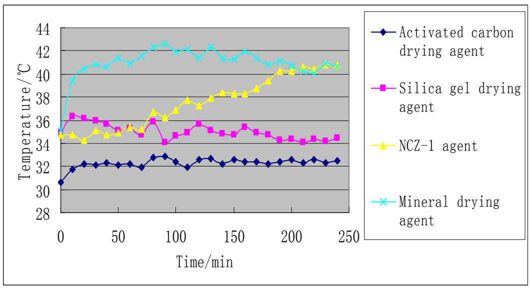

Fig. 12 Changing curve of temperature for drying agent

It is known from Fig. 11 that activated carbon drying agent and silica gel drying agent reach the first hygroscopic balance point around 60 minutes after starting the test, and reach the second hygroscopic balance point around 150 minutes. In the tendency of the curve, hygroscopic rate is unstable, and stable dehumidification is not available in the flatly-laid state. When the test is stopped, dehumidizer has nearly been moisture-absorbed to saturation point, and hygroscopic curve is level basically.

It is known from Fig. 11 that weight of NCZ-1 agent and mineral drying agent increases with time constantly. The weight-changing curve goes up by the positive tendency basically, and the uptrend of curve for mineral drying agent is more stable and mild. But due to test time, the dehumidification saturation point for NCZ-1 agent and mineral drying agent are not measured in 240 minutes. This is verified by the further test.

b. Temperature changes in the hygroscopic process of dehumidizers

In the refuge chamber, not only should dehumidizers satisfy requirements of humidity control, but also should not release heat to reduce the heat load in the dehumidification process. For this reason, temperature changes with time for four dehumidizers should be recorded in the test process, and the heat released from dehumidizers should be compared for analysis. The results by comparison are used as important indexes to select dehumidizers used appropriately for the refuge chamber. Temperature changes with time for four dehumidizers are shown in Fig. 12.

It is known from test results that the temperatures can keep stable changes basically for activated carbon drying agent, silica gel drying agent and mineral drying agent in the test, while for NCZ-1 agent, its temperature goes up significantly with a certain heat load in the hygroscopic process. In addition, surface temperatures for activated carbon drying agent and silica gel drying agent are lower in the test process, changing between 31~33℃ and 34~37℃ respectively, while the surface temperature for mineral drying agent is higher with big interval, changing between 39~43℃. As NCZ-1 agent's surface temperature-time curve goes up all the time, its upper temperature limit is not yet determined.

c. State changes of dehumidizers in the hygroscopic process

In the test process, there is no evident change of state for activated carbon drying agent, silica gel drying agent and mineral drying agent in the test. Their state in the test ending is the same as the initial states basically. When the test is done in 60 minutes, the activated carbon drying agent becomes wet slightly, and begins to adhere to the tray wall. After that, the activated carbon keeps its state unchangeable till the test ends. In 60 minutes, NCZ-1 agent starts to become molten state in most part, forming partial hardened matter. The mineral drying agent keeps its state unchangeable as a whole, but its agent grains become soft due to absorbed moisture. When it is pressed by the outside force, it becomes muddy matter as shown in Fig. 13. Till the test ends, external forms for activated carbon drying agent, silica gel drying agent and mineral drying agent change a little, while NCZ-1 agent is molten heavily in the test.

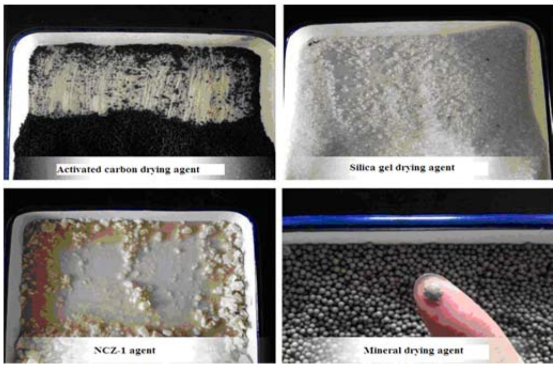

Fig. 13 State of four dehumidizers set on the trays in the test

From the hygroscopic capacities, activate carbon is lowest in efficiency; though silica gel drying agent is higher in moisture absorption, its total consumption is one time or more higher than that of NCZ-1 agent or mineral drying agent for the equal total hygroscopic capacity because of its lower stacking density. NCZ-1 agent is higher relatively in hygroscopic rate, but it releases heat and is gradually molten in the hygroscopic process. The mineral drying agent is preferable in the hygroscopic property in the comparative test, with significant effect. In addition, it is stable in property in the hygroscopic process, and can satisfy all requirements to select dehumidizers for the refuge chamber. However, due to limitation of the test time, the limited value of the hygroscopic efficiency for mineral drying agent is not measured. So in the future test, we should study further hygroscopic property of mineral drying agent, and measure its optimal configuration parameters.

5. CALCULATION FOR APPLICATION OF DEHUMIDIZERS FOR REFUGE CHAMBER

Take an example of the permanent refuge chamber in Area I6 of Kong Village Coalmine, and calculate total moisture gain of the refuge chamber as follows:

$$W = W_1 + W_2 + W_3 = 16.66 kg/h$$

According to the emergency rescue standard at the humidity reduced from 90% to 70% in the protective time of 96 hours, total dehumidification amount in theory is:

$$W' = (90\% - 70\%)96W = 320kg$$

The permanent refuge chamber in Area I6 of Kong Village Coalmine was set with four sets of air purifiers. The mineral drying agent was arranged in the air purifiers by high and low layers for dehumidification, and its dehumidification effect could reach 30% of its own weight. Thus, total amount of mineral drying agent should be:

$$M = W' \div 30\% = 1066.7kg$$

The use amount of mineral drying agent should be controlled in the air purifier as 2.5cm per layer (upper and lower layers arranging). When hygroscopic coefficient is assumed as 30%, the number of replacement per hour should be got as:

$$k = \frac{(90\% - 70\%) \times 1000W}{30\% M \times 4} = \frac{(90\% - 70\%) \times 1000 \times 16.66}{30\% \times 1.145 \times 5 \times 73.5 \times 34 \times 4} = 0.194$$

It can satisfy requirements of dehumidification inside of the refuge chamber that the agent is replaced once every five hours.

Conclusion

In the paper, the refuge chamber can be considered as the confined space with constant temperature and humidity without external conditions supporting, and the humidity control test was simulated in the constant temperature and humidity lab. Based on the results of manned test, main conclusions are drawn as follows through theoretical analysis on the humid load for the refuge chamber during coalmine underground disaster:

a. It is found from the manned test that the RH goes up significantly in the underground confined space during mine disaster, constantly coming to 80% or more, which has important influence on refugee's health, psychology and behaviors during disaster;

b. It is proposed that constituents and calculation of humid load for the mine refuge chamber, and humid load is calculated taking an example of the permanent refuge chamber in Area I6 of Kong Village Coalmine,

c. Through comparative analysis on common drying agent tests in the special environment, the results show the mineral drying agent is the best dehumidizer used for the underground refuge space. With calculation of replacing time and use level of the dehumidizer, we propose 1066.7kg agent is changed once every five hours, which can satisfy the humid control for the refuge space with 100 personnel at 96 hours.

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