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Potassium superoxide oxygen generation rate and carbon dioxide absorption rate in coal mine refuge chambers

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ABSTRACT

The effects of the molding pressure of a KO_2 oxygen plate and the initial concentration of CO_2 on the oxygen generation rate, the oxygen generation efficiency, and the carbon dioxide absorption rate were studied using a YES-300 hydraulic press to alter the pressure when forming the oxygen plate used in a coal mine refuge chamber. In addition, changes in the initial concentration of CO_2 used in the closed-box model were made by adjusting the CO_2 supply system, and a CD-7 multi-function parameter instrument was employed to monitor and record the changes of O_2 and CO_2 concentration in the closed-box model. Results indicate that the oxygen generation rate of KO_2 oxygen plates, the oxygen generation efficiency, and the carbon dioxide absorption rate decrease when there is an increase in the pressure used to mold the oxygen plates, but those values increase when the initial CO_2 concentration increases. When the initial concentration of CO_2 in the closed-box model is 3.5% and the forming pressure is 10 kN, the average oxygen generation rate of 15 g KO_2 oxygen plate is 11.88×10^{-3} L/min, the oxygen generation efficiency is 80.3%, and the average CO_2 absorption rate is 11.0×10^{-3} L/min. Compared with the condition where the initial CO_2 concentration is 1.5%, the results show that average oxygen generation rate of oxygen plates increases by 88.9%, the oxygen generation efficiency increases by 88.9%, and the CO_2 absorption rate increases by 100%.

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1. Introduction

An adequate oxygen supply in coal mine refuge chambers is essential for survival [1,2]. The most common types of oxygen supply systems in under-mine refuge chambers include ground drilled oxygen supply system, dedicated pipeline oxygen supply system, oxygen generating and purifying system, and chemical oxygen supply system [3,4]. The chemical oxygen system which is a backup oxygen source is small in size, easy to use, relatively steady reactions, and has a relatively low cost [5,6]. The most common types of chemical oxygen supplies used in airtight spaces include the potassium superoxide (KO_2) oxygen supply, chlorate oxygen supply, alkaline electrolyte of electrolytic water oxygen supply, and the solid electrolyte of electrolytic water oxygen supply [7-13]. As potassium superoxide (KO_2) can react with H_2O and CO_2 to generate O_2 and hydrocarbons and eliminate CO_2 at the same time. Therefore, it is used as the preferred chemical oxygen supply in under-mine refuge chambers. In this respect, the potassium superoxide (KO_2) was selected to use in this study. Previous studies have developed an oxygen supply device using KO_2 in relation to its oxygen generating and carbon dioxide absorbing features, and research results have been applied for using in submarines, aircrafts, spaceships and other enclosed space fields, as well as personal protection fields [14]. China began conducting related research into the use of KO_2 in the late 1950s, and self-rescuers and other oxygen supply devices built on the reaction principle of KO_2 have been used in mine rescue operations, the aerospace industry, plateau oxygen supplies, and other fields. However, China has not yet conducted further research in relation with the factors which affect oxygen generation and carbon dioxide absorption performances of KO_2.

Selecting a KO_2 oxygen plate as the object of research, a YES-300 hydraulic press, carbon dioxide tank and other devices were employed both in changing the molding pressure of the KO_2 oxygen plate in experiments and altering the initial concentration of CO_2 in an enclosed-space model. The closed-box model and the CD-7 multi-function parameter instrument were used to monitor and record the changes of O_2 and CO_2 concentration in the model [15]. In addition, this paper analyzed the molding pressure used for the KO_2 oxygen plate, the initial concentration of CO_2 in the

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model, the generation rate and efficiency of O_2, and the absorption rate of CO_2. Furthermore, we determined the molding pressure used to increase the O_2 supply performance for the KO_2 oxygen plate and improved the CO_2 absorption performance to provide a theoretical basis for research that related to chemical oxygen supplies in coal mine refuge chambers.

2. Experimental

2.1. Model

A closed-box model was used in which the experimental KO_2 oxygen plates were placed (Fig. 1) to determine the various molding pressures, the initial concentration of CO_2 and its influence on the generation rate and efficiency of O_2, and the CO_2 absorption rate for the KO_2 oxygen plates. The closed-box model is a cube of 600 mm × 600 mm × 600 mm, with a total volume of 216 L, and it consists of a main box, a humidifier, three casing pipes used to enclose a power line, a signal line and an air tube, an observation window made of explosion-proof glass used in submarines, steel seal rings and an airtight door. In these experiments, the CD-7 multi-function parameter instrument and the experimental KO_2 oxygen plates were inserted into the main box. The airtight door was sealed with tightened silicone pads and screws to prevent any gas from leaking.

2.2. Methodology

Eqs. (1)–(3) present the principles used for O_2 generation and CO_2 absorption of KO_2 [16,17]. KO_2 reacts with H_2O in air, then generates KOH and O_2; KOH reacts with CO_2 in air, generates K_2CO_3, $KHCO_3$ and H_2O; and the cycle is repeated until all the KO_2 has consumed. In order to study the effect of the used molding pressure and the initial concentration of CO_2 in closed-box model on the following reactions, experiments were performed in relation with the following procedures:

$$2KO_2 + H_2O \rightarrow 2KOH + 1.5O_2 + Q \tag{1}$$

$$2KOH + CO_2 \rightarrow K_2CO_3 + H_2O + Q \tag{2}$$

$$KOH + CO_2 \rightarrow KHCO_3 + Q \tag{3}$$

In the first experiment, the following method was used. Two samples of 15 g pure KO_2 powder were placed into a round oxygen plate-pressing model with a diameter of 6 cm. The YES-300 digital display hydraulic pressure compressed the KO_2 powder into an oxygen plate (Fig. 2), and the pressure was set to 10 kN and 20 kN [18]. A piece of the oxygen plate was placed into the closed-box model in every experiment, the airtight door was closed, the screw pads were tightened, the inserted tubes were sealed, and the humidifier was turned on simultaneously with the humidity set to 75%. The CO_2 tank was opened and the box was filled with an initial CO_2 concentration of 1.5%. The CD-7 multi-function parameter instrument was switched on, and the concentration changes of O_2 and CO_2 in the closed-box model were tracked and recorded in real-time. The average O_2 generating rate of the oxygen plate, the oxygen generating efficiency and the CO_2 absorption rate were calculated by Eqs. (4)–(6). Finally, the relationship between the oxygen plate molding pressure and the above three factors were analyzed.

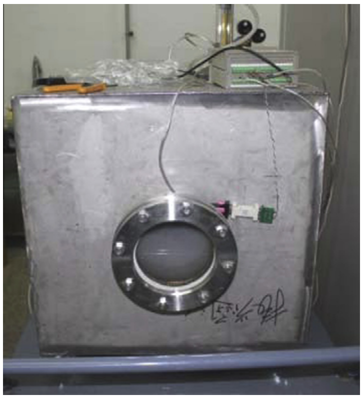

Fig. 1. Closed-box model.

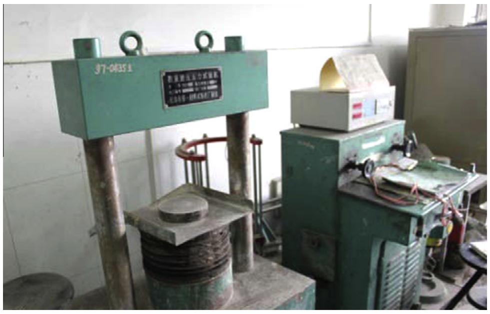

Fig. 2. Oxygen plate press machine.

$$w_{O_2} = \frac{c_{f_{O_2}} - c_{i_{O_2}}}{\Delta t} \tag{4}$$

$$w_{CO_2} = \frac{c_{i_{CO_2}} - c_{f_{CO_2}}}{\Delta t} \tag{5}$$

$$\eta_{O_2} = \frac{v_a}{v_t} \times 100\% \tag{6}$$

where w_{O_2} is the average oxygen generation rate of the KO_2 oxygen plate, L/min; w_{CO_2} the carbon dioxide absorption rate of the KO_2 oxygen plate, L/min; $c_{i_{O_2}}$ the initial concentration of O_2,%; $c_{f_{O_2}}$ the final concentration of O_2,%; $c_{i_{CO_2}}$ the initial concentration of CO_2,%; $c_{f_{CO_2}}$ the final concentration of CO_2,%; Δt is the test time, min; η_{O_2} the oxygen generation efficiency of the oxygen plate,%; V_a the actual total volume of oxygen generated by the oxygen plate, L; and V_t the theoretical total volume of oxygen generated by the oxygen plate, L.

In the second experiment, the optimal pressure was determined through the molding pressure experiment. Two samples of 15 g pure KO_2 powder were weighed and compressed into two pieces of the oxygen plates under the optimal pressure. One piece was placed into the closed-box model when the initial concentration of CO_2 was set to 1.5%. The other piece was placed into the closed-box model when the initial concentration of CO_2 was set to 3.5%. The CD-7 multi-function parameter instrument was then set to track and record the concentration values of O_2 and CO_2 in the closed-box model in real-time. The average oxygen generation rate, oxygen generation efficiency and CO_2 absorption rate were then calculated based on Eqs. (4)–(6), and the relationship between the initial concentration of CO_2 and the above three factors were analyzed.

3. Results and discussion

3.1. Effect of the molding pressure on the oxygen supply and carbon dioxide absorption of the oxygen plates

3.1.1. Effect of molding pressure on oxygen supply

As shown in Figs. 3 and 4, with an 1.5% initial CO_2 concentration, the reacted KO_2 oxygen plates with two different modeling

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