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Analysis of vacuum chamber suppressing gas explosion

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ABSTRACT

In order to suppress the harm of gas explosion, the current study researched on the body of vacuum chamber. The previous studies verified that it could obviously lower the explosion overpressure by reasonably arranging vacuum chamber on pipe. That is to say, the vacuum chamber has the effect of absorbing wave and energy. To further deeply analyze the vacuum chamber suppressing gas explosion, this research designed the L-type pipe of gas explosion, and compared the experimental results of gas explosion with vacuum chamber and without vacuum chamber. Besides, using the gas chromatograph, this study also investigated the gas compositions in the pipe before and after explosion. The results show that: (1) without vacuum chamber, the maximum value of explosion overpressure is 0.22 MPa, with 60 ms duration, and after explosion, the concentration of oxygen drops to 12.07%, but the concentration of carbon monoxide increases to 4392.3×10^{-6}, and the concentration of carbon dioxide goes up to 7.848%, which can make the persons in danger suffocate and die; (2) with vacuum chamber, explosion overpressure drops to 0.18 MPa, with 20 ms duration or less, and after explosion, the concentration of oxygen still remains 12.07%, but the concentration of methane is 7.83%, however the concentration of carbon monoxide is only 727.24×10^{-6}, and the concentration of carbon dioxide is only 1.219%, at the this moment the concentration ratio of toxic gas drops by more than 83% in comparison to be that without vacuum chamber. Consequently, the vacuum chamber can guarantee that most methane does not take part in chemical reaction, and timely quenches the deflagration reaction of gas and oxygen. Because of the two points mentioned above, it reduces the explosion energy, and lowers that the overpressure of blast wave impacts and damages on the persons and facilities, and also decreases the consumption of oxygen and the production of the toxic gas. Therefore, it is safe to conclude that the vacuum chamber not only absorbs wave and energy, but also prevents and suppresses explosion.

1. Introduction

Gas explosion is one of coal mine accidents which easily result in gravely casualties and property loss. At present, many researchers at home and abroad studied the occurrence mechanism and the law of gas explosion, and concluded abundant research results [1–7]. Prevention and suppression of explosion is key point of studying gas explosion. Ye et al. researched water mist on suppressing gas explosion in the use of a field-scale pipe [8]. The experimental results showed that the suppression effects depend on the density and length of water mist suspended inside the pipe, and both passive and active explosion suppressors can fully quench the explosion of methane–air mixture with the filling of enough water. Mikhail Krasnyansky researched on a very effective powder "powder for suppression of explosions" (PSE) for the suppression of explosion [9]. The experiments on suppression of explosion of a methane–air mixture (MAM) at a laboratory conditions using PSE-powder have been carried out. Rudolf Klemens et al. pointed out the following question: the industrial installations are additionally endangered by an action of mechanical vibrations [10]. In the above-mentioned conditions, the extinguishing powder tends to aggregate, making the process of dispersing powder in the protected areas more difficult. Because of that, the current study optimizes the shape, number of igniters and miniaturization of the explosive charge mass, and increases the efficiency of the explosion-suppressing process. Nie et al. designed a rectangular explosion test pipe to investigate the explosion flame propagation characteristics in empty pipe and in the presence of Al_2O_3 and SiC foam ceramics, and concluded that the foam ceramics drastically attenuated the maximal explosion overpressure by up to 50% [11]. Liu et al. focused on the suppressing effects on methane/coal dust/air mixture explosions of three solid-particle suppressing agents, and resulted in the conclusion that methane/coal dust/air explosions can be efficiently suppressed by the suppression agents characterized by the rapid decrease in overpressure and propagating velocity of the explosion waves [12]. Although the technology

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of prevention and suppression of explosion has made some progress, the traditional methods, such as trough, water bag, stone-dust barrier and so forth, are main ways of controlling or weakening the gas explosion in coal mine [13–15]. However, those methods are passively explosive-proof and they only lower the temperature of flame and cannot achieve a good result.

This study proposes a device that has an obviously good effect in explosion suppression by means of experiments, that is, vacuum chamber. The results show that this device can reduce the explosion overpressure remarkably, and also absorb the wave and energy, so this device can be taken as an explosion suppression apparatus which is active defense and ideal effect [16–18]. In order to analyze the suppression effect of vacuum chamber in detail, the study established L-type pipe of gas explosion, and carried out the experiments of gas explosion with and without vacuum chamber. In addition, gas composition was analyzed in the use of gas chromatograph, and revealed the effects of explosion suppression of vacuum chamber.

2. Experimental explosion suppression of vacuum chamber

2.1. Experimental system

The experimental system consists of the following devices: experimental pipe, vacuum chamber, air distribution system, flammable gas lighting system, dynamic data acquisition system, pressure test system, flame velocity test system and gas sample acquisition system, and the framework of this system is shown in Fig. 1.

The experimental pipe of gas explosion is 12 m long, and the cross section of this pipe is a flat square with 80 mm × 80 mm. Besides, this pipe uses four kinds of pipes with 0.5, 1, 1.5, 2.5 m, respectively. In order to strengthen flame and pressure signal, barrier ring was set in the range of 0.5 m from ignition end of experimental pipe. This study only analyzed the open mouth experiment. Thus, ignition end of experiment pipe was sealed, but the exit end of experiment pipe was totally open. The flame and pressure sensors were equally set on the experimental pipe, and Tables 1 and 2 show the position of each sensor. In other words, the position of each sensor is just the measuring point in the pipe. In order to analyze the gas composition before and after explosion, three measuring points were set in the pipe, and the position of each measuring point is illustrated in Table 3. And Fig. 2 shows the photo in the experimental process.

One end of vacuum chamber was sealed, and the other end of it was a weaker face. This weaker face was the flange plate embedded with armorplate glass which has certain thickness. Because the armorplate glass is easily fragile and has the characteristics

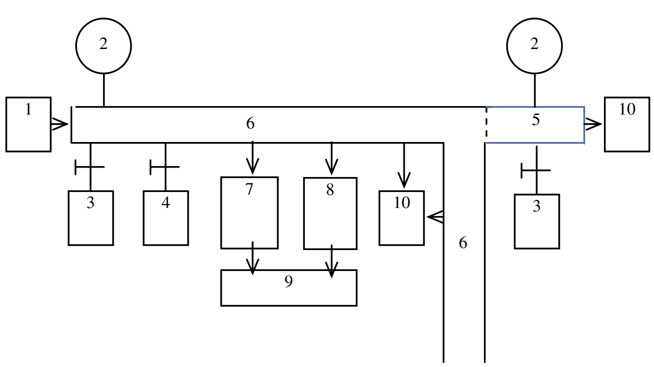

Fig. 1. Experimental components. 1. Igniter; 2. Vacuum gauge; 3. Vacuum pump; 4. Air distribution system; 5. Vacuum chamber; 6. Experimental pipe; 7. Pressure test system; 8. Flame speed test system; 9. Dynamic data acquisition system; 10. Gas sample acquisition system.

Table 1
Positions of flame measuring points in the pipe without vacuum chamber (m).

No.	*F*1	*F*2	*F*3	*F*4	*F*5
Distance from ignition end	0.670	2.325	3.125	4.625	7.125

Table 2
Positions of flame measuring points in the pipe without vacuum chamber (m).

No.	*P*1	*P*2	*P*3	*P*4	*P*5	*P*6
Distance from ignition end	0.775	2.175	3.325	4.825	7.325	Vacuum chamber

Table 3
Positions of gas sample acquisition points in the pipe without vacuum chamber (m).

No.	*G*1	*G*2	*G*3
Distance from ignition end	1.315	4.175	Vacuum chamber

Fig. 2. Photo in the experimental process.

of hardness, it is taken as the weaker face of interface between vacuum chamber and experimental pipe. When the blast wave produced by gas explosion passes the weaker face, this face will quickly fracture, which makes the vacuum chamber suppress explosion. The vacuum chamber was arranged at the position of 3 m from the ignition end.

2.2. Experimental procedures

(1) Check the gas tightness of experimental pipe and vacuum chamber. Before experiment, the pipe was exhausted and dried, and aerating the positive pressure air into sealed pipe is to determine whether air leakage occurs or not.
(2) Install and adjust the data acquisition system. Checking each pipe of acquisition system is to guarantee that sensors can acquire data correctly.
(3) Prepare gas. Methane–air mixture was prepared as the concentration of 9.5%.
(4) Aerate gas and light fire in the pipe without vacuum chamber. Experimental pipe was sealed and vacuated until certain vacuum degree reached, and the pointer of vacuum gauge held still. At the moment, air filler valve was opened, and pre-made methane–air mixture was injected into pipe until the pointer of vacuum gauge was back to zero. At this moment, the valves of pipe and air sac were shut up. The gas was extracted from the mouth of gas sample acquisition and then analyzed, then waited for lighting the fire and explosion. Before detonating the methane–air mixture in