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Influence of vacuum degree on the effect of gas explosion suppression by vacuum chamber

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ABSTRACT

In order to study the influence of vacuum degree on gas explosion suppression by vacuum chamber, this study used the 0.2 mm thick polytetrafluoroethylene film as the diaphragm of vacuum chamber to carry out a series of experiments of gas explosion suppression by vacuum chamber with the vacuum degree from −0.01 MPa to −0.08 MPa. The experimental results show that: under the condition of any vacuum degree, vacuum chamber can effectively suppress the explosion flame and overpressure; as vacuum degree changes, the effect of gas explosion suppression using vacuum chamber is slightly different. Vacuum chamber has obvious influence on propagation characteristics of the explosion flame. After explosion flame passes by vacuum chamber, the flame signal weakens, the flame thickness becomes thicker, and the flame speed slows down. With the increase of the vacuum degree of vacuum chamber, the flame speed can be prevented from rising early by vacuum chamber. The higher the vacuum degree is, the more obviously the vacuum chamber attenuates the explosion overpressure, the smaller the average overpressure is, and the better effect of the gas explosion suppression is. Vacuum chamber can effectively weaken the explosion impulse under each vacuum degree. From the beginning of −0.01 MPa, the vacuum chamber can gradually weaken explosion impulse as the vacuum degree increases, and the effect of gas explosion suppression gradually becomes better. When the vacuum degree is greater than −0.04 MPa, the increase of vacuum degree can make the explosion overpressure decrease but have little influence on the explosion impulse. Therefore, the vacuum chamber has the preferable suppression effect with equal to or greater than −0.04 MPa vacuum degree.

1. Introduction

Coal bed methane (CBM) has garnered significant worldwide interest as a low-carbon energy source. The proven reserves of the CBMs in China are 37 trillion cubic meters, ranking third in the world. Unfortunately, the Chinese CBM reservoirs have low permeability, low porosity and high in-situ stress owing to the effects of a complex geologic structure and burial conditions. This leads to low concentration of CBM (Cheng Zhai et al., 2015). The concentration of 70% CBM in the Chinese coal mines is lower than 30%, even lower than 20% in some Chinese coal mines. Due to CBM concentration inequality, this CBM is easy to fall within the explosion concentration range, and has the potential safety hazard in the process of transport and discharge. Gas explosion of CBM occurred in Shanxi, Chongqin, Anhui, Yunnan, etc. (Huo Chunxiu, 2014).

The method usually used to suppress CBM explosion in pipe is to spray explosion suppression materials into the reaction area of gas explosion in a timely manner. At present, the effective suppression materials, as verified by experiments, are water mist, inert gases, inert dust, and cellular materials. A significant decrease of H, O, and OH in the flame front can inhibit gas explosion caused by the presence of water (Liang and Wen, 2010). The grain size of water mist influences its effectiveness with respect to explosion suppression (Chelliah et al., 2002). Several groups have investigated the effects of the density and distribution of water mist on its ability to suppress an explosion (Ye et al., 2005; Catlin, 2002; Schwer and

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Kailasanath, 2007; Pengpeng Zhang et al., 2014). Ni, Ar, CO_2, and their mixtures influence the flame-out effects of *n*-heptane and methane-air and propane-air mixtures (Saito et al., 1996). Wang et al. discussed the ability of He, Ni, vapor and CO_2 to suppress explosion, and the principle of detonation was further discussed by Wang et al. and by Yu et al. (Wang and Duan, 2008; Yu and Chen, 2008). The explosion suppression principle and the effect of inert dust were also explored (Linteris et al., 2002; Krasnyansky, 2006); Liu et al., for example, investigated the explosion suppression effect of different inert dusts (Liu et al., 2013). Yu et al. observed that a multilayer wire mesh structure suppressed the explosion of premixed acetylene-air and propane-air gases (Yu et al., 2008). Nie et al. investigated the effect and the mechanism of foam ceramics used for suppressing gas explosions (Nie et al., 2011). Wei et al. reported that a porous material suppressed gas explosion flame waves (Wei et al., 2013). Luo et al. forced on the coupling explosion suppression by CO_2 and ABC powder (Luo et al., 2014).

Our research team has developed a new method for suppressing gas explosion via a vacuum chamber. The vacuum chamber is attached to the side of a gas explosion pipe and is separated from the gas explosion pipe by a diaphragm. The vacuum chamber is evacuated to a vacuum state. When a gas explosion occurs, the diaphragm is broken and the explosion flame is extinguished because of the vacuum pumping action; the gas explosion is thereby suppressed. Our results show that the vacuum chamber can obviously decrease the explosion overpressure and has the effect of absorbing shockwaves and energy; therefore, it is considered an effective explosion suppression apparatus (Jiang et al., 2008; Wu et al., 2009, 2012; Shao et al., 2013). The study used an L-type pipe and firing pin to guarantee that the diaphragm of vacuum chamber broke in time, and investigated the correlation between the break time of the diaphragm and gas explosion suppression by vacuum chamber (Shao et al., 2014). However, we still found that an L-type pipe and firing pin disturbed the gas in pipes, and caused complex explosion overpressure and flame, which was not beneficial to analyze the performance of gas explosion suppression. To this end, this research used polytetrafluoroethylene film as the diaphragm of vacuum chamber. Because the polytetrafluoroethylene film has little break strength, and can break in time without the firing pin. Thus, experiments can be carried out in straight pipe, which can't disturb the gas in pipe. The study used straight pipe without firing pin to conduct experiments of gas explosion suppression when the vacuum degree ranges from −0.08 MPa to −0.01 MPa, and contrastively analyze the effects of gas explosion suppression under the condition of different vacuum degrees.

2. Experimental apparatus

2.1. Experimental system

The experimental explosion system primarily contains the devices as follows: a straight pipe, vacuum chamber, circulating pump, flammable gas ignition system, dynamic data acquisition system, pressure test system, flame speed test system, and diaphragm. Fig. 1 shows the framework of this system. A photograph of the experimental system used in the experiments is shown in Fig. 2.

The experimental pipe is 11.5 m long, and its cross section is an 80 mm × 80 mm flat square. The vacuum chamber was installed in the pipe. In this study, we only conducted experiments with the outlet open. Thus, the ignition end of the experimental pipe was sealed, but the outlet end was completely open. Fig. 3 shows a schematic of the experimental pipe.

One end of the vacuum chamber was sealed, and a diaphragm was positioned at the other end. In past experiments, glass-made diaphragm was used. But, glass has higher strength, and can't break easily. Thus, it needed to add firing pin in the experimental pipes (Shao et al., 2014). The firing pin can increase turbulence intensity, which results in higher explosion overpressure and more complicated flame structure. Therefore, it is difficult to further study the gas explosion suppression using vacuum chamber. To this end, the present study used polytetrafluoroethylene film as diaphragm (Fig. 4). Different thicknesses of polytetrafluoroethylene film have different pressure-tolerance strengths. After measuring, the pressure-tolerance strengths of 0.1 mm, 0.2 mm and 0.3 mm thick films are in the ranges of 0.04–0.05 MPa, 0.08–0.09 MPa, and 0.15–0.16 MPa, respectively. When the pressure acted on the polytetrafluoroethylene film is higher than the value of pressure-tolerance strength, the film will break. According to the measuring results, 0.2 mm thick polytetrafluoroethylene film was chosen as the materials of diaphragm to carry out experiments. Fig. 5 shows the broken polytetrafluoroethylene film after gas explosion suppression occurred. The pressure-tolerance strength of polytetrafluoroethylene film becomes smaller when it meets flame or high temperature media, it is easy to break, even causes itself to melt or burn. Therefore, polytetrafluoroethylene film is only used for experimental study, while rupture disc is applied for field application because of its simple structure, easy install, good airtightness, and high-temperature tolerance.

The flame arrival time and flame signal strength were recorded using photodiodes (referred to herein as flame transducers) (Blanchard et al., 2010). The response spectrum of the flame transducers ranges from 340 nm to 980 nm, and the response spectrum time is less than 0.1 ms. Fig. 6a shows the flame transducers positioned along the pipe and a typical obtained signal. The overpressure was monitored using an array of piezoresistive pressure transducers. The pressure transducers were calibrated using a pistongauge. Fig. 6b gives a typical calibration curve that represents the relationship between the recorded voltages and the corresponding explosion overpressures (Zhu et al., 2012). Equal numbers of flame and pressure transducers were inserted into the experimental pipe; the position of each transducer is shown in Tables 1 and 2, and in Fig. 3.

2.2. Experimental procedure

(1) The air tightness of the experimental pipe and vacuum chamber were checked. Before the experiments, the pipe was dried and positive pressure air was aerated into the sealed pipe to determine whether air leakage occurred.
(2) The data acquisition system was installed and adjusted.
(3) The methane-air mixture was prepared at a concentration of 9.5%.
(4) The gas mixture was aerated into the pipe and detonated without the installed vacuum chamber.
(5) The gas mixture was aerated into the pipe and detonated with the installed vacuum chamber. The diaphragm made by 0.2 mm thick polytetrafluoroethylene film was used, and experiments were carried out when the vacuum degree successively changed from −0.08 MPa to 0.01 MPa, then contrastively analyzed the effects of gas explosion suppression in different vacuum degrees.

3. Results and discussion

3.1. Curves of explosion flame and overpressure

Fig. 7 shows the curve of flame and overpressure of gas explosion under different vacuum degrees. When the vacuum degrees are −0.08 MPa, −0.07 MPa, −0.06 MPa, −0.05 MPa, −0.04 MPa,