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Suppression of gas explosion using vacuum chamber at different break-up times of diaphragm

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ABSTRACT

Vacuum chamber is a new method to suppress the gas explosion. The explosion propagation characteristics have been studied in an L-shaped channel (tubes joined a right angle) with a vacuum chamber in the region of joining of the tubes. The vacuum chamber separated from the inner tubular space with the help of a diaphragm pierced by firing pin. The results demonstrate that the effect of explosion suppression of vacuum chamber is related to the break-up time of diaphragm and the position of the explosive flame front. When the diaphragm breaks up, the shorter the distance of flame front propagation is, the closer the flame front gets to the vacuum chamber, and the better effect of explosion suppression is, conversely, the worse the effect of explosion suppression is.

1. Introduction

Pipe is an important apparatus used for transmitting flammable gas, and it is used widely in the world. It may occur that pipe break results in gas explosion, which cause huge disasters. A lot of gas is emitted during the coal mining. Gas explosion is one of coal mine accidents that can easily cause the casualties and property loss.

The final goals of the suppression of gas explosion are as follows: how to quickly extinguish the explosive flame, prevent the explosion process from spreading, and weaken the explosive overpressure. The research on the suppression of gas explosion is mainly two aspects: one is to study the suppression apparatuses of gas explosion; and the other one is to investigate the suppression materials.

As for the studying suppression apparatuses of gas explosion, the goal is that how to spray the suppression materials into the reaction area of gas explosion timely, accurately and equably. Jingfang Ye et al. discussed the suppression effects with different arrangements for passive explosion suppression by water mists (Ye, Chen, Fan, & Xie, 2005). Klemens et al. studied the developed super fast extinguishing system that used the suppressing powders as the extinguishing material, optimized the apparatus structure, and avoided that the extinguishing powder tends to aggregate (Klemens et al., 2000). And, Klemens et al. also optimized the parameters of extinguisher which used extinguishing powders to increase the efficiency of the explosion-suppressing process in the action of mechanical vibrations (Klemens, Gieras, & Kaluzny, 2007).

The study of suppression materials mainly focuses on the suppression principle, influence factors of suppression performance, and improved method. At present, the effective suppression materials verified by experiments are water mist, inert gas, inert dust and cellular materials. Thomas researched on the relation between water mist explosion suppression and gas explosion strength (Parra, Castro, Mendez, Villafruela, & Rodríguez, 2004; Thomas, 2000). Chelliah et al. studied that grain size of water mist influenced on the effect of explosion suppression (Chelliah, Lazzarini, Wanigarathne, & Linteris, 2002). Several studies investigated that the density and distribution of water mist influenced on the effect of explosion suppression (Catlin, 2002; Schwer & Kailasanath, 2007; Ye et al., 2005). Saito et al. studied that nitrogen, argon, carbon dioxide and their mixtures influenced on the flame-out effect of n-heptane, methane–air and propane–air (Saito, Ogawa, Saso, Liao, & Sakei, 1996). Jian Wang et al. discussed the helium, nitrogen, vapor and carbon dioxide on the inert performance and

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principle of detonation flame (Wang & Duan, 2008; Yu & Chen, 2008). Linteris et al. explored the explosion suppression principle and effect of inert dust (Krasnyansky, 2006; Linteris, Knyazev, & Babushok, 2002). Chen drew on the explosion suppression effect of different inert dust (Chen, Fan, & Jiang, 2006; Liu, Hu, Bai, & Chen, 2013). Jianliang Yu et al. studied that multi-layer wire mesh structure suppressed the explosion of the premixed acetylene/air and propane/air gases (Yu, Cai, & Li, 2008). Baisheng Nie et al. investigated the effect and the mechanism of foam ceramics in suppression of gas explosion (Nie, He, Zhang, Chen, & Zhang, 2011). Chunrong Wei et al. examined that the porous material suppressed the gas explosion flame wave (Wei, Xu, Wang, Sun, & Fan, 2013).

Our research team finds a new method of suppressing gas explosion, that is, vacuum chamber. A vacuum chamber is added at the side of gas explosion pipe, and it is separated from gas explosion pipe by a diaphragm. Besides, the vacuum chamber is vacuated into vacuum state. When the gas explosion occurs, the diaphragm breaks up, and the explosion flame goes out because of vacuum pumping action, so the gas explosion is suppressed. The results show that: the vacuum chamber can obviously lower the explosion overpressure and has the effect of absorbing wave and energy, so it can be taken as an effectively explosion suppression apparatus (Jiang et al., 2008; Shao, Jiang, Li, & Wu, 2013; Wu et al., 2009). Previous experiments found that: whether the diaphragm can breaks up or not in time is the key point to influence the vacuum chamber suppression of gas explosion, but until now there is no quantitative research. To this end, this study designed L-shaped pipe and firing pin. Adjusting the length of firing pin can adjust the break-up time of diaphragm. This paper also researched on the suppression effect of vacuum chamber under different lengths of firing pins, and investigates the correlation between break-up time of diaphragm and vacuum chamber suppression of gas explosion.

2. Experimental apparatus

2.1. Experimental system

The experimental explosion system primarily consists of the following devices: rectangular pipe, vacuum chamber, circulating pump, flammable gas lighting system, dynamic data acquisition system, pressure test system, flame speed test system, gas sample acquisition system, diaphragm and firing pin. And the framework of this system is shown in Fig. 1. The experimental system used in the experiment is shown in Fig. 2.

The experimental pipe is 12 m long, and its cross section is a flat square with 80 mm × 80 mm. At the turning of the pipe, the vacuum chamber is installed. In order to strengthen explosion's reaction speed, 0.5 long barrier ring was set at the ignition end of experimental pipe. This study only analyzed the experiment with outlet open. Thus, the ignition end of experimental pipe was sealed, but the outlet end of it was totally open. A schematic diagram of the experimental pipe is shown in Fig. 3.

Fig. 2. Photo of system layout.

One end of vacuum chamber was sealed, and the other end of it was a diaphragm. This diaphragm was the flange plate embedded with annealed glass. When the shockwave produced by gas explosion passes the diaphragm, this diaphragm will quickly break up, which makes the vacuum chamber suppress explosion, as shown in Fig. 4. The vacuum chamber was set at the position of 3 m from the ignition end, as noted in Fig. 3.

After the gas explosion occurs, the diaphragm suffers from the effect of overpressure. When the overpressure reaches certain value, the diaphragm will break up, and vacuum chamber comes into play. If the explosion overpressure is relatively small and the diaphragm does not break up or the break-up time is postponed, the vacuum chamber does not play a role. To this end, this study designed a firing pin. Fig. 5(a) shows the structure of the firing pin, and the firing pin consists of compression face, conducting rod and metal cusp. The length of firing pin can be adjusted by conduct rod. Fig. 5(b) presents the size of 0.5 m long firing pin. Fig. 3 displays the position of firing pin. The firing pin can amplify the pressure of shockwave that diaphragm suffers from, and make the diaphragm break up in time.

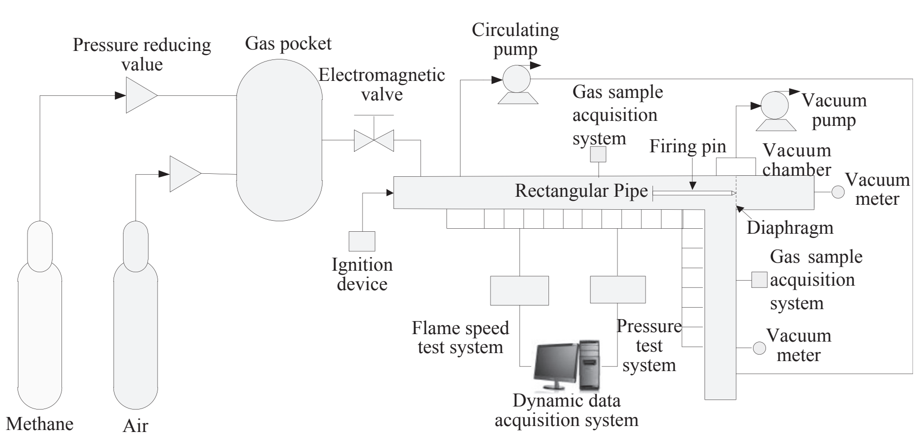

Fig. 1. Experimental components.