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Application and effect of negative pressure chambers on pipeline explosion venting

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ABSTRACT

Explosion venting is a frequently-used way to lower explosion pressure and accident loss. Recently, studies of vessel explosion venting have received much attention, while little attention has been paid to pipe explosion venting. This study researched the characteristics of explosion venting for Coal Bed Methane (CBM) transfer pipe, and proposed the way of explosion venting to chamber in order to avoid the influence of explosion venting on external environment, and investigated the effects of explosion venting to atmosphere and chamber. When explosion venting to atmosphere, the average explosion impulse 4.89 kPa s; when explosion venting to 0 MPa (atmospheric pressure) chamber, average explosion impulse is 7.52 kPa s; when explosion venting to −0.01 MPa chamber, explosion flame and pressure obviously drop, and average explosion impulse decreases to 4.08 kPa s; when explosion venting to −0.09 MPa chamber, explosion flame goes out and average explosion impulse is 1.45 kPa s. Thus, the effect of explosion venting to negative chamber is far better than that to atmospheric chamber. Negative chamber can absorb more explosion gas and energy, increase stretch of explosion flame, and eliminate free radical of gas explosion. All these can promote the effect of explosion venting to negative chamber.

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 et al., 2015). In Chinese coal mines, the concentration of 70% CBM is lower than 30%, even lower than 20%. 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).

Apart from the suppression measures to remove possible explosion threat in the CBM transfer pipe, explosion venting is also used to prevent from the damage of explosion overpressure after explosion suppression fails. Explosion venting denotes that the burnt high-pressure mixed gas in pipe or vessel is timely vented to external environment using explosion venting apparatus, which makes the internal pressure drop quickly, effectively guarantees the pipe or vessel safe, and reduces the loss caused by accident (Jiang et al., 2005; Kasmani, 2008). Explosion venting process couples the turbulent flow and oscillation burning of combustible medium which is influenced by fuel composition and proportion, vessel characteristics, pressure-relief outlet ratio, energy and position of ignition, barrier, etc (Tomlin et al., 2015; Tascón and Aguado, 2015; Wang et al., 2013; Huang et al., 2013). After explosion venting, some flammable gas may be vented to external environment, forming under-expanding jet which causes external fire and even external explosion in certain condition (Taveau, 2010; Quillatre et al., 2013). How to remove the burning and explosion outside outlet of explosion venting is the main question that explosion venting technology needs to solve (Snoeys et al., 2012; Chao and Dorofeev, 2015). For this reason, auxiliary device is usually added into the outlet of explosion venting, such as duct which is used to transport explosion venting gas to external atmosphere, avoiding damage to external device and personnel, but using this duct will influence the effect of explosion venting (Russo and Di

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Benedetto, 2007; Ferrara et al., 2008). Besides, poisonous and explosive gas cannot use explosion venting, only applied explosion suppression method, etc.

The previous studies focused on explosion venting of vessel, including mechanism of explosion venting and external explosion, etc (Fakandu et al., 2015; Bauwens and Dorofeev, 2014; Yan et al., 2014). Also some studies investigated pipeline explosion (Jiang et al., 2016a; Wang et al., 2015; Sun et al., 2015), including pipeline explosion suppression, that is, spraying explosion suppression inhibitor into the reaction area of gas explosion in a timely manner and using inhibitor to inhibit explosion propagation (Luo et al., 2014; Pengpeng Zhang et al., 2014; Du et al., 2014; Jiang et al., 2016b; Xu et al., 2016). Study of pipe explosion venting has rarely been addressed. Therefore, the present study investigated the explosion of CBM transfer pipeline, proposed a new way of explosion venting based on analyzing characteristics of traditional explosion venting ways, and contrastively studied the effect of different ways of explosion venting.

2. Way of explosion venting

The common way of explosion venting is that the high temperature and pressure mixed gas after explosion is vented to external environment, namely, atmospheric environment. This kind of explosion venting is called as explosion venting to atmosphere. In order to prevent the vented high temperature and pressure gas from damaging external device and personnel, flame arrester is added on the outlet of explosion venting, to extinguish the flame at outlet. Or, adding duct is to vent the high temperature and pressure gas to exterior of workshop. However, the methods mentioned above will increase explosion overpressure compared with explosion venting without auxiliary device, which will influence the effect of explosion venting (Snoeys et al., 2012; Chao and Dorofeev, 2015; Russo and Di Benedetto, 2007; Ferrara et al., 2008).

It is clear that explosion venting can effectively lower the explosion overpressure in vessel, and influence external environment. In order to eliminate this influence, explosion gas can be vented to airtight chamber. Yu et al., 2012 used spherical chamber to study this method, and concluded that the effect of explosion venting is the same as that venting to atmospheric environment when the volume of chamber was 5 times of explosion vessel. However, the disadvantage of this method is that chamber is too big, and takes up much room. We improved it, that is, the decrease chamber's pressure makes its lower than atmospheric pressure, which reaches the same explosion venting effect of expanding chamber volume.

In order to evaluate the effects of explosion venting with different ways, this study used pipeline explosion system to carry out the explosion venting to atmosphere, to atmospheric pressure chamber, and negative pressure chamber, and then contrasted characteristics of explosion venting with different ways.

3. Experimental program

In total, five large-scale explosion experiments were carried out (Table 1). Gas explosion in pipeline occurs with the condition of no explosion-venting apparatus, using to contrast with explosion venting. Explosion venting to atmosphere is that vents the explosion gas to atmosphere, only adding rupture disc at the outlet of explosion venting. Explosion venting to chamber is to vent the explosion gas to chamber, adding rupture disc and chamber at the outlet of explosion venting. With the condition of different pressures in chamber, three groups of experiments were carried out, that is, venting to 0 MPa chamber, to −0.01 MPa pressure chamber, and −0.09 MPa pressure chamber.

3.1. Experimental system

Experimental system contains pipeline explosion system and auxiliary device. Auxiliary device includes rupture disc and chamber. Different experiments involve the same pipeline explosion system and different auxiliary devices (Table 1). The pipeline experimental explosion system primarily contains the devices as follows: a straight pipe, circulating pump, flammable gas ignition system, dynamic data acquisition system, pressure test system, flame speed test system, and auxiliary device. Fig. 1 shows the framework of experiment pipe explosion venting to chamber. Fig. 2 presents a photograph of the experimental system used for explosion venting to chamber.

The experimental pipe is 11.5 m long, and its cross section is an 80 mm × 80 mm flat square. The total volume of the pipe is 73.6 L, which is nearly two times of chamber. Auxiliary device (namely, rupture disc and chamber) is added at the position that is 3.25 m to ignition point (Fig. 3). Rupture disc is 0.3 mm Polytetrafluoroethylene film (Fig. 4). The face of rupture disc is round with 120 mm diameter, and its pressure-tolerance strength ranges from 0.15 to 0.16 MPa. When the pressure acted on the rupture disc is higher than the pressure-tolerance strength, the rupture disc will break. Fig. 5 shows the broken rupture disc after gas explosion venting occurs. Chamber is 0.5 m long cylinder with 300 mm inner diameter and 38.33 L volume. After adding rupture disc, the gas in pipeline can directly vent to chamber when rupture disc breaks (Figs. 2 and 3).

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 to 980 nm, and the response spectrum time is less than 0.1 ms. Fig. 6a shows the flame transducers installed 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

Table 1
Experiment and corresponding apparatus.

Experiment	Experimental system			
	Pipeline explosion system	Using rupture disc	Using chamber	Pressure in chamber
Gas explosion in pipeline	Yes	No	No	
Venting to atmosphere	Yes	Yes	No	
Venting to atmospheric pressure chamber	Yes	Yes	Yes	0 MPa
Venting to −0.01 MPa pressure chamber	Yes	Yes	Yes	−0.01 MPa
Venting to −0.09 MPa pressure chamber	Yes	Yes	Yes	−0.09 MPa