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Effect of wire mesh on double-suppression of CH_4/air mixture explosions in a spherical vessel connected to pipelines

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ABSTRACT

Most inlets or outlets of tanks and reactors are linked vessels consisting of the tank or reactor itself and pipelines. In this study, a series of experiments was conducted to study the double-suppression effect of a multi-layer wire-mesh structure on methane-air mixture explosions in a spherical vessel connected to pipelines. The double-suppression effect was analyzed using explosion-suppression structures with different number of layers and meshes, and in particular, the effect was compared with the suppression of single-wire mesh. The results show that the explosion suppression effect primarily depends on both the number of layers and number of meshes. The number of layers plays a positive role in suppression when enough layers are used, and the number of meshes also has a significant effect on explosion suppression. It appears that the position of the wire mesh only has a slight effect on explosion suppression. The results provide a fundamental basis for actual explosion protection designs.

1. Introduction

In the modern industry production process, gas vessels are typically connected to pipelines, namely linked vessels. Explosions in linked vessels are much more violent than that in a single vessel (Wang et al., 2011, 2013; Oh et al., 2001). Lagutov et al. (1997) investigated the shock wave interaction with compressible polyurethane foam in a shock tube by a special optical method of visualization of transparent as well as nontransparent non-uniformities. He found that the thickness of compressed zone increases linearly with time. Zalosh (2007) added polymeric foams and an aluminum mesh in an apparatus to study explosion suppression. The results showed that a wall of porous material can weaken transverse waves but potentially cannot restrain the explosion. Zhang et al. (2014a,b) investigated the effects of nitrogen and argon on natural gas/air mixture explosion characteristics. The author noted that nitrogen exerts a greater inhibitory effect on the explosion than that of argon. The maximum explosion pressure of a gaseous mixture first increases then decreases as the concentration of natural gas increases, and the smaller the initial pressure is, the smaller the maximum explosion pressure is. Guo et al. (2002) investigated the propagation of gaseous detonation waves over tube sections lined with acoustically absorbent materials. The results show the increasing effectiveness of a perforated steel plate, wire mesh and steel wool in attenuating detonation. Zhu et al. (2014) performed a numerical simulation using the finite rate combustion model. When the quantity of CO_2 is less than 12 kg/s, the flame cannot be extinguished. Nevertheless, when the quantity of CO_2 is greater than 16 kg/s, the temperature of the gaseous mixture in the pipe decreases greatly. Furthermore, the concentration of methane and oxygen is reduced, which extinguishes the flame at the entrance position of the CO_2. Hojo (1986, 1984), and Tsuda and Hojo (1990) systematically investigated the extinguishing capability of multi-layer structures in pipelines. The results demonstrated the clear relationship between the extinguishing capability and the geometric parameters of the wire-mesh structure. The results also indicated that the materials have no effect on the extinguishing capability. In another study, a spherical vessel with a volume of approximately 20 L was adopted to study the explosion suppression of $Mg(OH)_2$ and CO_2 (Deng et al., 2013). It was discovered that $Mg(OH)_2$ and CO_2 have a certain inhibitory

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effect on gas explosions. A new geometrical simplification method for numerical simulations was proposed. Using the large amount of calculated pressure drop data, a new expression was derived for predicting pressure drops across mesh pads (Sun et al., 2015). The cellular structures of RDX–ethylene–air hybrid mixtures and ethylene–air mixtures were obtained with the use of smoked foils and exhibit irregular structures. It found that the measured cell size has a U-shaped curve with respect to RDX concentration (Yang et al., 2016). A multi-layer wire mesh greatly impacts the gas explosion flame propagation and may fully quench a weaker explosion flame. For a premixed gas mixture, experimental investigations into the suppression effect of multi-layer wire-mesh structures in pipes have been performed (Yu et al., 2008). The relationship between the critical values of the quenching speed and critical values of the quenching differential pressure, explosion suppression parameters, and geometrical parameters of multi-layer wire-mesh structures was also investigated.

However, all of the aforementioned studies only considered a single-suppression explosion with a simple explosion propagation process. However, linked vessels are diverse and complex, and the double-suppression effect has not been systematically taken into consideration. Therefore, in this paper, the double-suppression effect of a multi-layer wire-mesh structure on methane-air mixture explosions in linked vessels is investigated by conducting a series of experiments. In particular, the effect of the number of layers, number of meshes, and the position of the wire meshes are discussed in detail.

2. Experimental setup

2.1. Experimental apparatus

A test system was built to measure the explosion pressure of a methane-air mixture. The measurement system consists of a spherical vessel connected to pipelines, an ignition device, a gas distribution system, a pressure measurement unit, and a data acquisition and analysis system (standard test method for explosion parameters of flammable gases GB/T 803-2008; American Society for Testing and Materials (ASTM) ASTM E 681-04).

2.1.1. Explosion vessel

As illustrated in Fig. 1, the spherical vessel is 0.35 m in diameter, 0.016 m in thickness and 22 L in volume. There are three cylindrical pipeline sections that are 2 m in length, 0.06 m in internal diameter and 0.015 m in thickness. These components are connected by flanges. Nozzles on the spherical vessel and pipelines are used to set the pressure transmitters, vacuum manometers, spark plugs, gas inlet, and gas outlet. A rupture disk is installed at the end of pipeline to prevent the overpressure in the vessel from getting too high, which is a safety apparatus.

2.1.2. Ignition device

An XDH-6 storage battery is used as an electrical ignition source for the high-tension spark plugs, which ignite the flammable methane-air mixture. The ignition position is located in the center of spherical vessel, and the ignition energy is 6 J.

2.1.3. Gas distribution system

SY-9506, which is a distribution instrument, is used to obtain the mixture of methane and air at 10 percent of methane.

2.1.4. Pressure measuring unit

CYG1401MF pressure transmitters are used to measure the explosion pressure.

2.1.5. Data acquisition and analysis system

A JV5231 multi-channel data acquisition system is adopted to collect synchronous data, and the data analysis software DEW Soft 7.0 is used to process the data.

2.1.6. The procedure gas admixture

The main procedure of gas admixture is as follows. Firstly, the air in vessel is exhausted by the vacuum pump. The premixed gas of methane and air is made up by the compound gas system (SY-9506). And then the gas mixture is transferred into the apparatus until a gage pressure in the vessel is 0 MPa. Then the gas mixture is allowed to come to equilibrium by waiting at least 5 min before each test. SY-9506 is a compound gas system that could get the accurate solubility of methane-air mixture quickly by controlling each velocity of gas. It is used to get the mixture of methane and air with the concentration of 10%. The volume of the gas mixture vessel inside SY-9506 is about 2 L. Two concentration transducers are installed in this vessel to confirm the precision of the gas concentration.

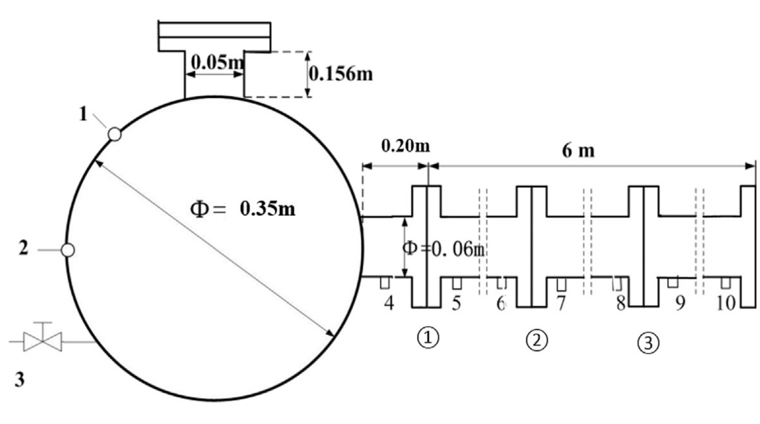

Fig. 1. Schematic diagram of explosion apparatus.