Journal of Loss Prevention in the Process Industries 54 (2018) 85–92

Contents lists available at ScienceDirect

Journal of Loss Prevention in the Process Industries

journal homepage: www.elsevier.com/locate/jlp

Effect of vent conditions on internal overpressure time-history during a vented explosion

Song Sun, Mingyang Wang*, Kanghua Gao, Tianhui Zhao, Qiang Guo

State Key Laboratory for Disaster Prevention & Mitigation of Explosion & Impact, The Army Engineering University of PLA, Jiangsu, Nanjing 210007, China

ARTICLE INFO

Keywords:
Vented explosions
Vent area
Rupture pressure
Pressure gradient

ABSTRACT

Vented explosion experiments of ethylene-air mixtures were conducted in a custom-designed $2 \times 1.2 \times 0.6\,m^3$ steel chamber under three vent conditions to study the effect of vent size and vent type on overpressure under different concentrations. The experiment results show that vented explosion behaviors are related to various vent conditions. The rupture pressure of vent film at different concentrations are the same with static vent pressure while the rupture pressure of vent panel increases as the concentration approaches the stoichiometric concentration. Double-peak pressure curves were recorded under small size vent conditions, while overpressure curves with only one peak were recorded under large size venting. Analysis indicates that the peak overpressure and rate of pressure increase under large size venting are mainly affected by the rupture pressure and the concentration of combustible gas, respectively. Moreover, secondary explosion, due to the backflow of external gas, will occur in high concentrations under large size vent conditions. In the case of small size vent condition, the value of first peak P_1 is mainly determined by the rupture pressure, while the value of second peak P_2, and the rates of increase to P_1 and P_2 are mainly affected by the concentration. There is a clear difference between the recorded values of P_2 at two measurement points, which indicates that there is a pressure gradient induced by small size vent conditions due to the change of flow cross-section. This work provide a practical reference for the safety design of the explosion venting.

1. Introduction

Combustible gases, such as: natural gas, coal gas, methane, ethylene, *etc*., have become among the most important sources of energy and the main raw material in chemical industry. At the same time, accidental explosions occasionally occur due to the characteristics of flammable and combustible substances in the process of usage, storage and transportation, which result in a serious threat to life and property.

When an accidental explosion occurs in an enclosed space, the extent of the ensuing damage mainly depends upon the magnitude of the overpressure transients and the duration of the loading event(s). Explosion venting is a commonly used method to prevent, or minimise, damage to an enclosure during an internal gas explosion. The vent pressure, vent area, and gas concentration exert significant influences on the internal gas explosion overpressure and the extent of the ensuing damage (Razus and Krause, 2001; Guo et al., 2015). A large number of experimental studies on vented explosions have been carried out and corresponding theoretical models have been developed (Ferrara et al., 2008; Middha and Hansen, 2008; Bauwens et al., 2010; Kim and Kim, 2004; Tamanini, 2001; Alexiou et al., 1997; Ambrosi et al., 2009; Forcier and Zalosh, 2000; Holbrow et al., 2000; Kim et al., 2013; Molkov and Bragin, 2015; Rota et al., 1991). Cooper et al. (1986) conducted vented explosions in near-cubic enclosures with low-rupture-pressure vent panels and a typical overpressure-time profile with four major overpressure transients was observed. Furthermore, it has been proved experimentally that each pressure peak is controlled by different physical mechanisms and the mechanism of generation of each pressure transient was explained. Guo et al. (2016) conducted gas explosion experiments in a cylindrical vented vessel, and the impact of Helmholtz oscillations caused by the pressure relief on internal pressure and shape of flame are investigated. Bao et al. (2016) investigated the effect of gas concentration and vent pressure on the overpressure-time profile in a $12\,m^3$ concrete chamber with a vent area of $0.64\,m^2$ filled with methane-air mixtures and four types of overpressure-time profiles with different pressure peaks were observed under different explosion and pressure-generation conditions. J. Chao et al. (2011) conducted vented explosion tests in a small-scale explosion vessel and a large-scale explosion chamber: they found that external explosions, acoustic oscillations, and the presence of obstacles are the dominant factors affecting the pressure transients and the influence of an obstacle, ignition

* Corresponding author. Haifu lane No.1, Qinghuai district, Nanjing city, Jiangsu province, China.
E-mail addresses: sunsongky23@163.com (S. Sun), wmyrf@163.com (M. Wang).

https://doi.org/10.1016/j.jlp.2018.03.002
Received 13 November 2017; Received in revised form 17 February 2018; Accepted 1 March 2018
Available online 03 March 2018
0950-4230/

position, and the discharge area on each peak are analysed. Zhang et al. (2017) carried out methane/air explosion experiments in spherical vessels connected with pipes to investigate the effect of pipe length on explosion suppression and found that vessel size, pipe length, and wire-mesh all have an effect on explosion suppression. Kobiera et al. (2007) assumes that the burning velocity of a turbulent wrinkled flame can be determined from the flame surface and derived a sub-model of turbulent burning velocity based on the assumption used to calculate the gas explosion pressure in an enclosed space. In a study by Ugarte et al. (2015), an overpressure computational model, considering vent sizes, container shapes, and ignition locations, is developed by correcting the flame area, flame propagation velocity, and external explosion pressure on the basis of a one-dimensional isentropic vent model: it was found that the modified model matches the experimental results.

From the aforementioned studies, current experimental studies are mainly carried out in a vessel or chamber with a venting to investigate the effect of explosion venting on the internal overpressure (Proust and Leprette, 2010; Jérôme et al., 2017; Harrison and Eyre, 1987); however, vent panel is rarely used in these experiments to study vented explosion in which a surface of chamber was broken entirely and little consideration is given to the effects of different vent types on the internal pressure. Meanwhile, the theoretical calculation model (Razus and Krause, 2001; Kobiera et al., 2007) and standard (NFPA 68) consider internal explosion pressures as everywhere consistent, the pressure gradient near the vent due to the change in flow cross-section is ignored and the mechanism and process of pressure change can not be clearly described. In this paper, experiments were conducted in a chamber with different vent conditions: the effect of vent area and vent type on internal pressure under different concentrations was investigated. In addition, rupture characteristics of vent panel, the explanation for secondary explosion and pressure gradient as well as their corresponding generation conditions are presented. This work make a supplement to the current research and provide a practical reference for the safety design.

2. Experimental work

2.1. Test apparatus

The test apparatus consists of: a gas distribution system, a rectangular explosion chamber, an ignition device, a vent cover, a pressure-measuring unit, and a dynamic data acquisition and analysis system. The schematic of the experimental apparatus is shown in Fig. 1.

A custom-designed $2 \times 1.2 \times 0.6\,m^3$ rectangular steel chamber with a design pressure limit of 1 MPa was constructed. The thickness of the explosion chamber wall was 50 mm, and one side of the chamber was sealed with a vent using a self-designed clamp-type flange. Polyethylene vent film and a calcium silicate vent panel with different vent areas were chosen to seal the vent according to experimental requirements. A strain gauge was attached to the back of the vent cover to record the vent rupture pressure and time. An igniter made of resistance wire was connected, by a flange, to the centre of the other side, which constitutes the ignition system (in which the ignition temperature was approximately 500 °C). Since most of the previous research focused on common fuels such as natural gas, coal gas, methane, *etc*. and rarely involve combustible raw material in chemical industry, ethylene, which is the core of petrochemical industry and widely used in the chemical industry, was selected as the combustible gas for this experiment. The chamber was evacuated by a vacuum pump through a suction hole and then filled with ethylene through multiple inlet holes equidistantly arranged on the side of the explosion chamber. The air-inlet hole are equipped with narrow-bore air-intake pipes, with small diameter holes disposed evenly around their circumferences. The concentration of the mixed gases was controlled by a flow meter and a pressure gauge: this air-intake system, with the use of uniformly distributed injection pipes, can guarantee the uniformity of the gas concentration in the chamber. The overpressures were recorded by two piezo-resistive pressure transducers (PCB113B26) mounted on the top of the chamber at distances 1.2 m (T_1) and 0.1 m (T_2) from the vent cover, respectively. The transducer surface was coated with silicone oil to ensure the reliability of the data measured in the high-temperature regime prevailing during the explosion. Electrical signals from the pressure transducers were registered by the data acquisition system and converted to pressure signals, which were sampled at a frequency of 200 kHz. A high-speed camera was placed 8 m from the vent cover of the chamber and its frame rate was set to 1000 fps.

2.2. Test procedures

The test procedures are shown in Fig. 2. After the vent cover was mounted, the suction valve was opened, and the vacuum pump was started to extract the gas from within the chamber. When the pressure in the chamber had reached the specified negative gauge pressure, the valve was closed and the pressure gauge reading was checked to detect the sealing of the explosion chamber. When the pressure gauge reading remain unchanged, the sealing of the chamber could be deemed acceptable. Ethylene was then injected into the explosion chamber by the method of partial pressure distribution and the gas injection system was closed when the ethylene in the chamber reached a specific concentration, as controlled by the flow meter. After an interval of 30 s, needed to achieve a low and consistent turbulence intensity (CR Bauwens et al., 2011), the pressure measurement system, high-speed camera, and data acquisition system were started and the ignition system was activated to trigger an explosion.

2.3. Test strategy

Since both the vent film and glass are instantaneous-open vent

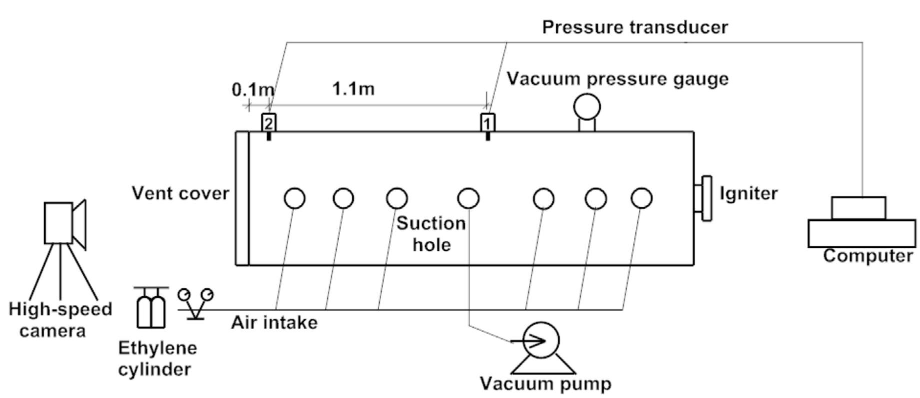

Fig. 1. Schematic of the experimental system.