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Suppressions of gasoline-air mixture explosion by non-premixed nitrogen in a closed tunnel

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A B S T R A C T

Suppressions of the gasoline-air mixture explosion by non-premixed nitrogen were studied experimentally in a closed tunnel. During the process of experiments, the test tunnel was divided into three parts by two plastic films: igniting section, N_2 suppression section and gasoline-air mixture section. Meanwhile, two flame intensity sensors were respectively deployed in front of and behind the N_2 suppression section. Based on the analysis of the flame intensities, overpressures and concentrations of the gas components after ignition, the gasoline vapor concentration range in which the explosions can be effectively suppressed, critical length of the ignition section and critical O_2 concentration in the suppression section were discussed in detail. It was indicated that values of maximum overpressure and overpressure rise rate of the explosions with non-premixed suppression were lower than that without such suppression. When the initial gasoline vapor concentration is constant, the critical length of the ignition section increases with the growth of the length of the N_2 suppression section. The relationship between the critical length of the ignition section and the initial gasoline vapor concentration can be described as a negative exponential expression of $y = ae^{-bx}$. There are three modes for the explosion suppression experiments: complete suppression mode, partial suppression mode and suppression failure mode. The critical O_2 concentration in the N_2 suppression section decreases with increase of the λ (a dimensionless parameter of ignition section length/N_2 suppression section length) when the initial gasoline vapor concentration is 2.0%.

1. Introduction

Gasoline, one of the most extensively used fuels, is volatile and can form a flammable gas mixture with air easily. Statistics indicates that more than 55 serious gasoline-air mixture fire or explosion accidents occurred from 1960 to 2003 (Chang & Lin, 2006). In the past decades, explosions of gasoline-air mixture were still common safety accidents leading to serious casualties and huge economic losses. For example the Buncefield oil depot explosion accident in London in 2005 (Johnson, 2010), Indian Oil Corporation Ltd. explosion accident in 2009 (Sharma, Gurjiar, Wate, Ghuge, & Agrawal, 2013) and Qingdao oil pipeline explosion accident in China in 2013 (http://www.chinadaily.com.cn/china/2013-11/23/content_17125977.htm), etc.

In view of frequently occurred safety accidents in recent years, explosion suppression is still a significant issue and some effective passive or active suppression methods are consequently proposed to prevent losses from these accidents. Whether passive or active methods, both need a suppressant or device to mitigate or extinguish the flame propagation effectively (Moore, 1996). In the references related to explosion suppression, liquid and solid suppressants are two common suppression agents. Water mists and sprays are primary liquid suppressants for fires and explosions and have already been studied in many aspects (Catlin, 2002; Parra, Castro, Mendez, Villafruela, & Rodriguez, 2004; Shimizu, Tsuzuki, Yamazaki, & Hayashi, 2001; Thomas, 2000; Thomas, Edwards, & Edwards, 1990; Wingerden, Wilkins, Bakken, & Pedersen, 1995; Ye, Chen, Fan, & Xie, 2005). Solid suppressants mainly include various particles (Chen & Fan, 2005; Dong, Fan, Xie, & Ye, 2005; Liu, Hu, Bai, & Chen, 2013) and powders (Krasnyansky, 2006; Deng, Pu, Luo, & Cheng, 2012; Wang, Wen, Wang, & Sun, 2012; Yu, Wang, You, & An, 2011). Explosion suppressions by mitigating devices usually need to deploy some special material in the path of flow before the occurrence of explosion. These suppression materials mainly include expanded metal mesh and polymer foam (Robert, 2007), expanded aluminum product (Birk, 2008), foam ceramic (Nie, He, Zhang, Chen, & Zhang, 2011) and porous medium (Zhang

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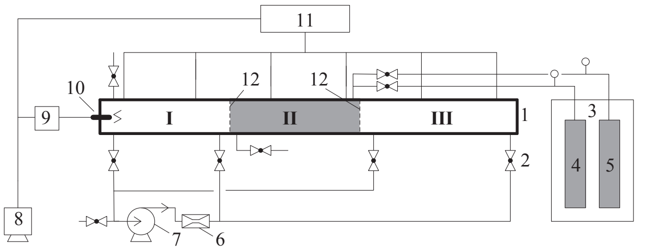

1. Test tunnel; 2. Valve; 3. N_2 production system; 4. N_2 container; 5. O_2 container; 6. Gasoline evaporation apparatus; 7. Vacuum circulating pump; 8. Computer; 9. Ignition system; 10. Spark plug; 11. Data acquisition system; 12. Plastic film; I. Ignition section; II. N_2 suppression section; III. Gasoline-air mixture section.

Fig. 1. Schematic of experimental apparatus.

et al., 2011), etc., It is worth mentioning that Jiang et al. (2008) and Wu et al. (2009, 2012) designed a closed vacuum chamber structure for explosion suppression with a fragile plane on the base of the suction of vacuum. They found that when the vacuum chamber was used the maximum overpressures of the methane explosion and the specific impulses of shock wave were greatly reduced, compared to that when the vacuum chamber was not used.

Nitrogen is inert, stable and non-reactive and widely used to provide an inert atmosphere and prevent explosions and fires in many cases. Some studies on its inert characteristic (Li, 2001; Razus, Brinzea, Mitu, Movileanu, & Oancea, 2009; Su & Liu, 2001) and dilute effect (Molnarne, Mizsey, & Schröder, 2005; Razus, Molnarne, Movileanu, & Irimia, 2006; Zhang et al., 2013) as it is premixed with flammable gas for the purpose of preventing fires and explosions have been reported. In these studies, nitrogen usually was used as a premixed dilute agent rather than a non-premixed suppressant, and as a consequence, the suppression performances of nitrogen when it is used as a suppression agent for flammable gas explosions are seldom involved. In addition, among all the studies mentioned above, research works have commonly involved methane, propane and other flammable gas or dust mixed with air but gasoline vapor is seldom considered.

The purpose of this paper is to experimentally study the suppression (or mitigation) performances of the nitrogen for gasoline-air mixture explosions in a closed tunnel with a segment of non-premixed nitrogen and provide data from such experiments.

2. Experimental equipments and methods

The experimental equipments used in this article mainly consisted of tunnel, gasoline evaporation apparatus, vacuum circulating pump, data acquisition system, ignition system and computer, as shown schematically in Fig. 1. The tunnel was composed of six parts with a same cross section dimension of 200 × 200 mm and total length was 6100 mm, and the structure and dimension of the test tunnel was shown in Fig. 2.

The gasoline evaporation apparatus and vacuum circulating pump were used to form a uniform gasoline-air mixture in the test tunnel. Details of structure and working principle of the gasoline evaporation apparatus can be found in reference Zhang et al. (2013) or Du, Zhang, and Ou (2013).

Fig. 3. The flame intensity sensor.

The data acquisition system mainly consisted of pressure transducers, flame intensity sensors, concentration collection system and acquisition card with measuring accuracy of 0.1% and dynamic response time of 1 ms. The explosion history was recorded by three pressure transducers arranged along the test tunnel, and the average values of the three transducers' records were used to represent the overpressures of explosion suppression in the tunnel. The flame intensity sensor was mainly composed of a photodiode, a base and a signal line, as shown in Fig. 3. The photodiode could detect ray radiations of the flame in ranges of ultraviolet to infrared lights, and transformed these light signals into voltage signals. Before the experiments, all flame intensity sensors were calibrated by a UNI-T381 digital luxmeter (Uni-Trend Group Limited).

The concentration collection system was mainly composed of a GXH-1050 infrared analyzer (Junfang physicochemical Science and Technology Institution of Beijing) and a NHA-502 automotive emission analyzer (Nanhua instruments Co. Ltd.). Concentration of the gasoline vapor was obtained by the GXH-1050 infrared analyzer, and other gaseous concentrations were collected by the NHA-502 automotive emission analyzer.

The ignition system consisted of spark plug, power and high voltage which could give a maximum ignition energy about 20 J. The ignition energy and position of the ignition source had a significant effect on the initial propagation of the flame and the resulting flame speeds and overpressures (Phylaktou & Andrews, 1991a, 1991b), so it was set at a constant ignition energy of 10 J and kept at a constant position flush at the center of one of the blind flanges.

The nitrogen and oxygen used in the experiments were separated from air and generated by a nitrogen production system (Shanghai Rich gas equipment Co. LTD). The purities of the nitrogen and oxygen were about 95%–99%. During the course of the experiment, the tunnel was divided into three parts by two plastic films:

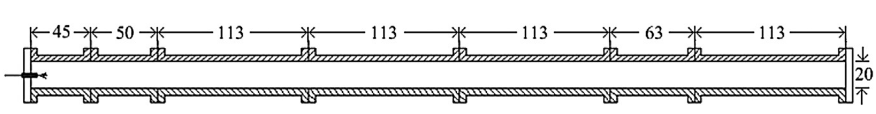

Fig. 2. Structure and dimension of the test tunnel.