Experimental Study on Active Deflagration Suppression Technology in an Open Tube

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1 Introduction

Deflagration in industrial process involving flammable gas is a threat, such as gas explosion in coal mine roadway, deflagration in gas transmission tube and so on [1,2]. Research on active deflagration suppression technology in the tube is the key to prevent flame propagation, reduce deflagration range and prevent deflagration from changing to detonation. The researches of the deflagration flame propagation and deflagration suppression in small tubes, such as oil and gas tubes, are relatively mature. Christian Lohrer [3] studied the effect of the tube length on the flame acceleration of propane/air premixed gas. The experimental study of Kris Chatrathi [4] showed that the flame velocity and pressure were closely related to the equivalence ratio of the premixed gas in a straight tube. Thermal expansion and turbulent flow also influence the flame propagation. In the aspect of deflagration suppression, the suppression effect of fire extinguishing particles on gas explosion in the tube under different conditions was studied by Krasnyansky et al. [5]. Chelliall [6] and Oleszczak [7] respectively studied the deflagration suppression process of coalbed methane/air mixture and dust/air mixture. However, due to the limitation of experimental scale and cost, the studies of deflagration and suppression process were mainly carried out in small tubes. The research of deflagration suppression technology is still very limited in large tubes such as coal mine roadways with the diameter more than 2m and length more than 20m and more complex environment.

This work aims to study the active deflagration suppression technology suitable for large diameter (more than 2m) tubes. It can automatically detect the deflagration fire and start the deflagration suppression system within 10 ms. The deflagration suppression particles can be injected completely within 10 ms. A uniform particles barrier with an area of 3 m^2 and a certain thickness can be formed within 60 ms to prevent the acceleration and propagation of deflagration flame. The experiments on deflagration and deflagration suppression of LPG/air premixed gas in an open tube with a diameter of 2.6m and a length of 25m was carried out to verify the effectiveness of deflagration suppression technology.

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2 Research on Active Deflagration Suppression Technology

The deflagration suppression is achieved by forming a fire extinguishing particles barrier with a certain thickness in front of the deflagration flame. Because the velocity of deflagration flame can reach tens or even hundreds meters per second, the technology of active deflagration suppression lies in the realization of the flame detection, particles injection and barrier formation in a very short time (ms level).

2.1 Flame Detection Technology

Flame detection technology was realized by the optical detector. The flame optical detector consisted of a flame light sensor and an explosion-proof aluminium shell and was wrapped with the heat-insulating asbestos cloth. The appearance of the flame detector is shown in Figure 1.

Figure 1. The appearance of the flame detector.

The infrared signal of 4.0-4.8 um wavelength is collected by the optical sensor and converted into analog signal by photoelectric conversion. The luminescence test of the initiating explosive was carried out, and the reaction time of the flame detector was measured by the high-speed photography, as shown in Table 1. The flame detector can detect deflagration flame within 1.5m in 10 ms.

Table 1: Reaction time of flame detector

Code	Distance between Flame Detector and Initial Explosive (m)	Ignition time (ms)	Detection time of flame detector (ms)	Reaction time of flame detector (ms)
1	0.5	8	10.4	2.4
2	1.5	13	20.8	7.8

2.2 Quick Start Technology

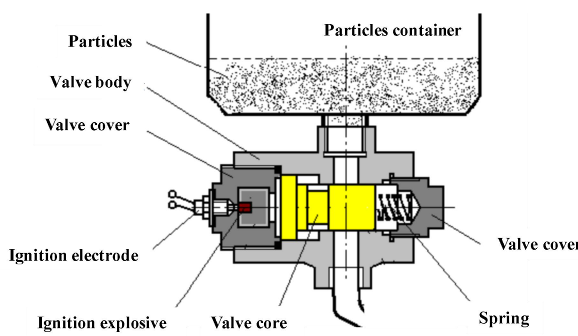

Figure 2. The principle diagram of quick start valve.

Quick start technology refers to the quick start of the valve connecting the suppression particles storage devices and the injection devices. The start-up time is the key affecting the formation of the particles barrier. The instantaneous high-pressure impulse generated by the explosion of the initiating explosive propels the valve core to move, so that the valve can be opened quickly. The schematic diagram is shown in Fig. 2. The test results showed that the opening time of the valve is 2 ~ 5 ms. Since the valve receives the starting signal, the particles can be injected in about 10 ms.

2.3 Injection Technology of Effective Particles

The ultra-fine ABC dry powder was selected as the suppression particles. Compared with the ordinary dry powder, the ultra-fine ABC has a smaller particle size, which is more conducive to diffusion in the space. The injection process of particles depends on the structure of the spray disc, as shown in Figure 3. The shape of the spray disc is octagonal and 8 long strip cavities connect the vertexes and center of the octagon. The angle between the adjacent cavities is 45 degrees, which ensures the overall stability of the injection. Each cavity has six circular channels connected to the nozzles. The particles can move in different directions to form a uniform particle barrier.

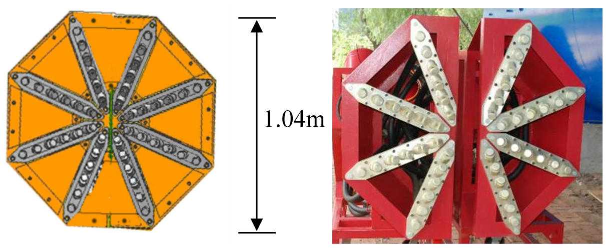

Figure 3. The spray disc of particles.

The injection process recorded by the high-speed camera is shown in Fig. 4. It can be seen that the range of particles was approximately a sphere, which indicates that the particles were dispersed uniformly in the space and can form a barrier in a short time. The experimental results showed that the particles barrier with an area larger than 3 m^2 can be formed within 60 ms.

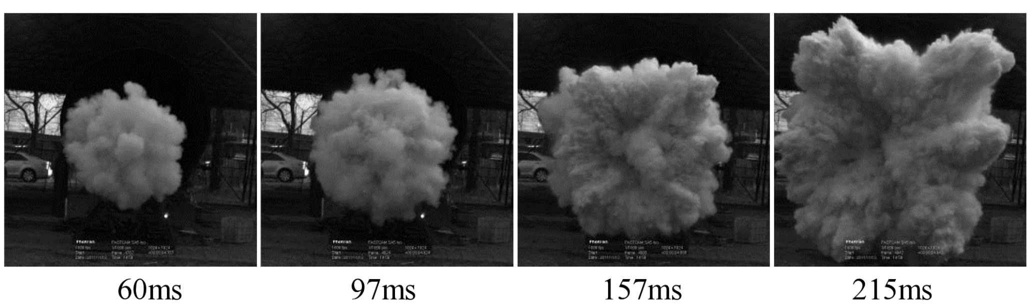

Figure 4. Formation of the suppression particles barrier.

3 Experimental Study

The structure of the active deflagration suppression device is shown in Fig. 5. The effectiveness was verified by the experiments of deflagration and suppression in an open tube.

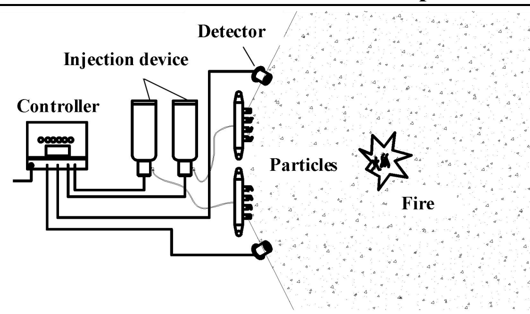

Figure 5. The structure diagram of deflagration suppression device.

3.1 Experimental System

The diameter and length of the tube were 2.6 m and 25 m, as shown in Fig. 6. A spark igniter was installed at the center of the closed end. The temperature sensors were set at 2.0 m intervals along the axis, numbered T1-T7. The length of deflagration chamber was 4 m and the volume was 21.24 m³. The concentration of LPG was 6%, and the distance between deflagration-suppression location and deflagration chamber was *DL*=6.5m. The weight of deflagration suppression particles was 40kg.

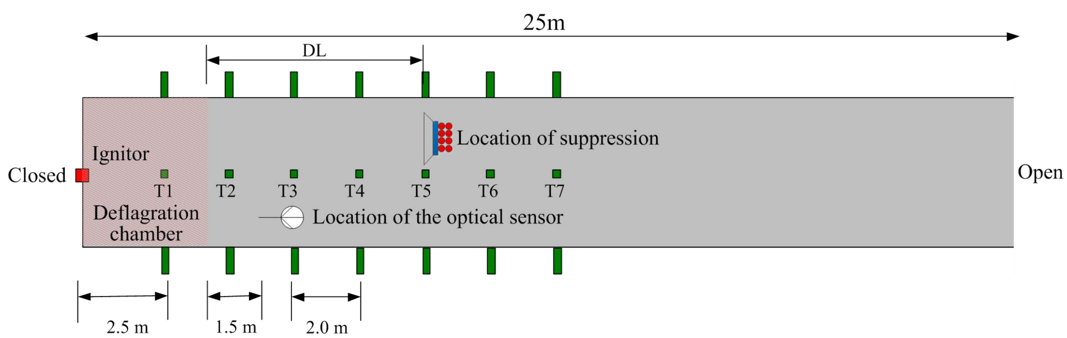

Figure 6. The experimental system of ϕ 2.6m*20m.

3.2 Experimental results

The flame propagations in deflagration experiment and deflagration suppression experiment are shown in Fig. 7. The obvious flame was observed at the four observation windows and the outlet of the tube without suppression. After suppression, there was no flame passing through the observation windows, and only white smoke appeared at the outlet. It is proved that the suppression device can inhibit the propagation of deflagration flame.

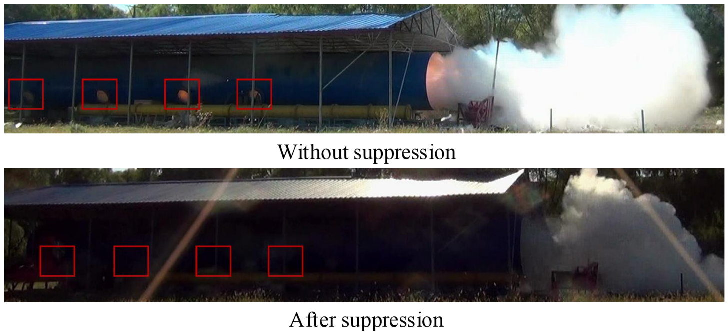

Figure 7. The flame propagation in the tube.

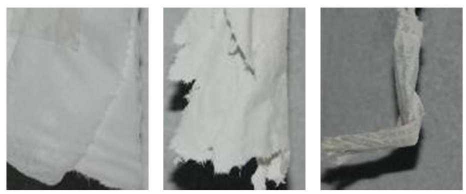

Figure 8. The damage degree of paper after suppression experiments.

(From left to right, the order is not damaged, slightly damaged and severely damaged.)

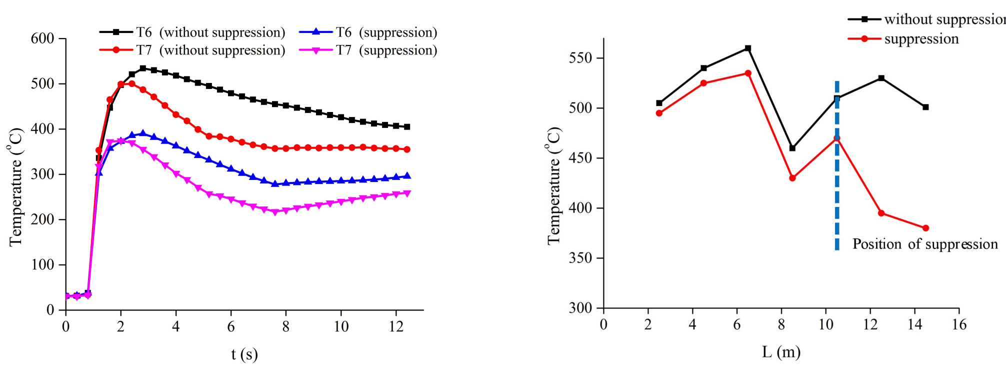

Figure 9. The temperature variation in the tube.

(Left: temperature behind the suppression position; right: maximum temperature at different locations in the tube.)

Along the direction of flame propagation, pieces of paper were fixed at 2 m intervals on both sides in the tube as markers. The differences of the damage degree of markers in the tube can more intuitively reflect the impact of deflagration suppression. All the paper fixed in the tube burned out without suppression, indicating that the deflagration flame filled the whole space. After suppression, the paper within 6-8 m from the ignition end (in front of the suppression location) were severely damaged, while those within 8-10 m (near the suppression location) were slightly damaged, and those after 10 m (behind the suppression location) were not damaged, as shown in Figure 8. It showed that the suppression technology effectively inhibited the damage of deflagration.

The temperature change behind the suppression position (T6, T7) is shown in figure 9. After suppression, the temperature decreased obviously. Besides, the maximum temperature decreased by more than 30% in the area 4 m away from the ignition position after suppression, which indicated that the suppression process had played a significant role in reducing the temperature in the area both before and after the suppression position.

4 Conclusions

The active deflagration suppression technology using the ultra-fine ABC dry powder was studied by experiments. The flame can be detected within 1.5 m in 10 ms, the particles can be injected within 10 ms, and uniform particles barrier with a certain thickness can be formed within 60 ms to achieve deflagration suppression. The suppression effect of the active deflagration suppression technology on the deflagration process of the LPG/air premixed gas was verified in an open tube with a diameter of 2.6 m and a length of 25 m by comparing the flame propagation, damage degree and temperature changes.The results showed that the deflagration of the LPG/air premixed gas with a volume of 21.24 m^3 and a concentration of 6% can be suppressed by 40 kg particles.

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