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Experimental research on water curtain diluting heavy gas dispersion in limited space with no ventilation

Min Qi [a, b], Taotao Yue [a, b], Min Hua [a, b], Xuhai Pan [a, b, *], Juncheng Jiang [a, b]

[a] College of Safety Science and Engineering, Nanjing Tech University, Nanjing 210009, Jiangsu Province, China
[b] Jiangsu Key Laboratory of Hazardous Chemical Safety and Control, Nanjing 210009, Jiangsu Province, China

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A B S T R A C T

Water curtains have been widely used in industries to prevent the release of heavy gas. It is very important to understand the dilution mechanism of water curtains and explore the setting parameters of the water curtains in a limited space. In this paper, experiments were conducted to explore the factors related to the dilution efficiency of water curtains. The results indicated that the dilution efficiency of a water curtain was about 80%. The dilution efficiency of fan spray nozzles was about 6% higher than that of cone nozzles. The dilution efficiency of single layer water curtains was about 1.7% higher than that of double water curtains. The dilution of a water curtain was the most efficient when the water spray nozzles were installed 1.2 m high. The higher the water pressure, the greater the dilution efficiency. The dilution efficiency of water curtains decreased with the distance between water curtains and the release source. When the CO_2 was released from 40 L/h to 160 L/h, the dilution efficiency would decrease from 88–89% to 78–79%.

1. Introduction

Heavy gases such as Cl_2, LNG, CO_2 are widely used in the petroleum and chemical industries. However, once released, heavy gas will spread along the ground and lead to poisoning, fire and explosion, especially in limited space. For example, in 2014, a methanethiol release accident happened in a factory of E. I. Du Pont Company in southeast Houston. Five workers were exposed to methanethiol gas directly. Four people were killed and one was hurt.

Plenty of theoretical and experimental research has been carried out to study gas release and the dispersion process (Qi et al., 2010; Gavelli et al., 2010; Hansen et al., 2010). Mathematical models of gas release and dispersion have been established (Dandrieux-Bony et al., 2005; Dandrieux et al., 2003; Scargiali et al., 2005). Rahmani Mariam and others (Rahmani and Cooper, 2004; Shih et al., 2009; Hefny and Ooka, 2009) researched the heavy gas dispersion process in a closed space by experiments and simulations. The pollutant dispersion law and concentration distribution in different conditions were analyzed. Deaves (Deaves et al., 2000) established the mathematical model of heavy gas dispersion in limited space.

Water curtains, as an effective technique to control and mitigate toxic and hazardous gas, have been used in many emergency accidental releases. It is confirmed that a water curtain is effective to absorb, dilute and disperse heavy gas. Some scholars found the mechanism of water curtain diluting and obstructing gas dispersion by simulation (Cheng et al., 2014; Morse and Kytömaa, 2011) and experiments (Olewski et al., 2011; Rana et al., 2008; Rana et al., 2010).

Factors of water curtain diluting and obstructing toxic and hazardous gases in open space were explored in previous research, but few research on it in limited space (Shih et al., 2011). Dimbour (Dimbour et al., 2003) evaluated the effect of water curtain inhibiting chlorine in limited space by experiments. The results indicated that dilution efficiency of a fan spray nozzle was the best in three different types of nozzles. Hald (Hald et al., 2005) explored the effect of different experiment methods on the dilution efficiency of water curtains.

If heavy gas were released in limited space, it would be difficult for the vapor clouds to spread and could lead to serious consequences. Considering safety in the experiments, CO_2, one common heavy gas in the chemical industry, was chosen as the typical case in this paper. Small scale field experiments were carried out to research the factors of water curtain diluting and obstructing heavy

* Corresponding author. College of Safety Science and Engineering, Nanjing Tech University, Nanjing 210009, Jiangsu Province, China.
E-mail address: xuhaipan@njtech.edu.cn (X. Pan).

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gas dispersion. The conclusions could provide reliable methods to set fixed water curtains properly in a limited space.

2. Experiments

2.1. Experimental system

The experimental system was mainly composed of a gas discharge system, a small-scaled limited space, a water curtain system and a CO_2 concentration detection system, as is shown in Fig. 1. The gas discharge system included a gas cylinder, a reducing valve, a rotor flow meter and piping. The reducing valve was connected between the cylinder and the rotor flow meter. The outlet diameter of the pipe was 6 mm CO_2 was provided by Nanjing special gas plant. The volume of the gas cylinder was 40 L and the pressure of the gas was 10.0 MPa. The volume fraction of CO_2 was 99%. The size of the space was 5 m × 1.6 m × 2.5 m (length × width × height). There were some tiny cracks at the corner and edge of the space, so the air pressure of the indoor space was equal to outside. The water curtain system was composed of a water supply system, nozzles, a pressure gauge, valves and flow meters. Two types of nozzles (fan spray nozzle and cone nozzle) were adopted in the experiments. The range of the flow meter was 300–3000 m^3/h. The model of the fan spray nozzle was ZSTM15A and that of the cone nozzle was ZSTWB34/60. The flow coefficient of both nozzles was 38. The CO_2 concentration detection system was composed of four CO_2 concentration sensors, a transmitter, a data acquisition machine and computer data processing system. The model of the CO_2 concentration sensor was JQAW4AC and the signal refreshed every 0.5 s.

2.2. Experimental process

The initial conditions of the experiments: The atmospheric pressure was 0.1 Mpa. The ambient temperature was 25 °C. The height of the release source was 0.8 m. The release rate of CO_2 was 120 L/h. 1.5 m apart from the release source, two nozzles were set on a movable pipe and 0.6 m apart from each other. Water curtains were installed 1.6 m high and the water pressure was 0.1 MPa. Water sprayed vertically down from the nozzles. Four concentration sensors were set as shown in Fig. 2. The experiment began when the volume fraction of CO_2 in the air was 0.038–0.042%. The dilution efficiency of the water curtain was measured by:

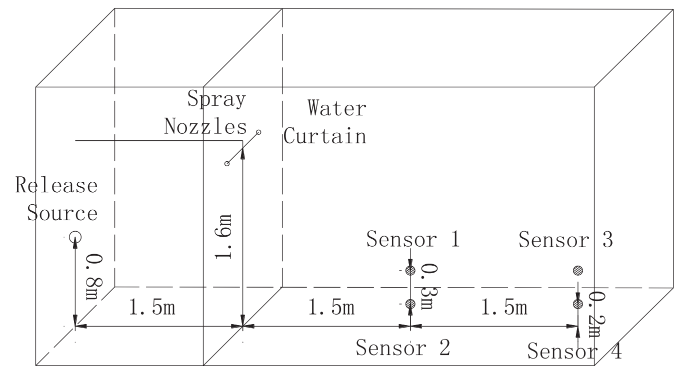

Fig. 2. Layout of CO_2 concentration sensors (unit: m).

$$\eta = (\varphi_0 - \varphi_1)/\varphi_0 \quad (1)$$

φ_0 and φ_1 represent the volume fraction of CO_2 before and after using the water curtain. The actual value was equal to the measured value minus the volume fraction of CO_2 in air.

3. Results and discussion

3.1. Water spray nozzles

With the same flow, the effect of different spray nozzles on the dilution efficiency was investigated. Fig. 3 shows the curve of CO_2 concentration changing with time at different nozzles. Table 1 shows the different dilution efficiency of water curtains.

It can be seen from Table 1 and Fig. 3 that water curtains can reduce CO_2 concentration greatly. The dilution efficiency of a fan spray nozzle was about 6% higher than that of a cone nozzle because fan-shaped sprays dilute CO_2 mainly by creating a barrier to the passage of the vapor cloud as well as imparting momentum to it. Water sprayed from nozzles gives momentum to vapor clouds and drives its spreading out. Cone sprays diluted CO_2 mainly by air entrained. Water sprays decomposed into droplets and had air entrained effect at the boundary of water curtains. Water gave momentum to ambient air and the air could reduce CO_2

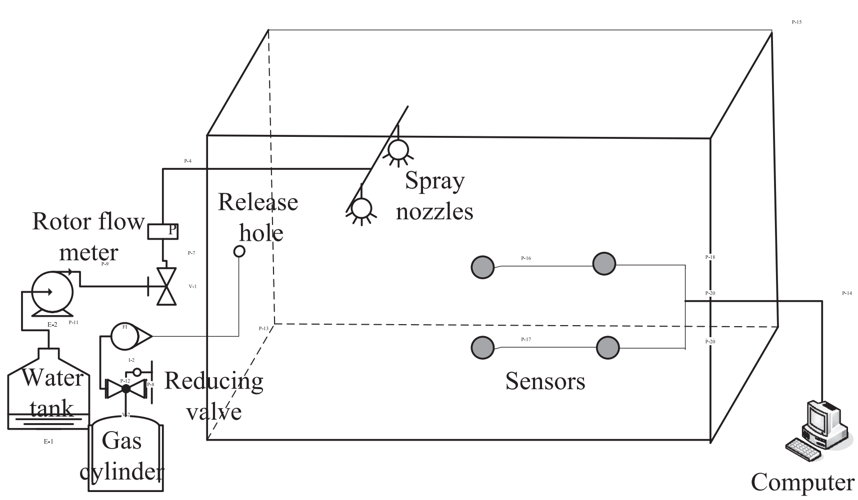

Fig. 1. The experimental system.