Experimental study on gas diffusion in subway station

Lei Wang [1,2], *Kun* Zhang [2], *Jinrui* Zhang [1], *Meng* Peng [2], *Jian* Kang [1,*], and *Jiayu* Xu [2]

[1]Research Institute of Chemical Defence, State Key Laboratory of NBC Protection for Civilian, Beijing, China
[2]Tsinghua University, School of Environment, Beijing, China

Abstract. In this paper, three-dimensional ultrasonic anemometer and multi-channel anemometer have been used to monitor the flow field of a subway station in Beijing. Based on releasing sulfur hexafluoride (SF6) in the station hall, the gas transmission and diffusion range have been studied. The results show that under the natural ventilation, the gas diffusion would be controlled by a regular mainstream field. Because of obvious subsidence heavy gas tends to accumulate on the ground. The airflow on the north side of the platform is stable, which may be the main channel for gas diffusion and the gas will not be transmitted downward to the platform. As a result, during emergency response During emergency disposal, it is necessary to set an evacuation path opposite to gas diffusion. Besides, it is forbidden to turn on the top smoke exhaust system to avoid the transmission of pollutant on the ground to the breathing height.

1 Introduction

In recent years, the development and utilization demand for underground space has increasingly grown due to the acceleration of urbanization [1]. Although the subway, underground store, and civil air defence work have greatly relieved the urban space pressure, the situation of preventing and dealing with unexpected environmental pollution events becomes more serious [2]. The release of pollution in indoor space (e.g., fire, leakage of a hazardous substance, deliberate poisoning, biological and chemical terrorist attack) is unexpected and accidental. Except for the fire explosion, others mostly release colourless and odorless gaseous pollutants with weak identification and strong diffusion. Due to unknown type, location and intensity of pollution source, complex and closed structure of underground space, large passenger flow density, and various air distribution, the unexpected gas pollutants will diffuse easily but cannot be exhausted outside, while the narrow channel and panic emotion will greatly reduce the efficiency of evacuation. Therefore, the casualty and influence of environmental events in underground space are far higher than common open space [3].

The subway station is taken as an example. Although the administrative department of each country has issued various policies, it is still difficult to implement prevention and

* Corresponding author: jiayu_tsinghua@163.com

control [4,5]. On 20 March 1995, the world-shaking sarin terrorist attack event occurred in the subway station of Tokyo. After being placed in 5 trains of 3 lines, the liquid sarin volatilized and diffused to the station platform after stopping. Over 13 passengers were dead, more than 5500 passengers were injured, and many passengers now still have the sequela of sarin. In November 2003, an unknown gas leakage occurred in the subway station of New York, and 6 staff were poisoned. In September 2006, CO leakage occurred in Jonggak Station of Seoul. Consequently, 39 passengers were poisoned because the gas leakage was not found for a long time. In September 2016, the suspected gas attack event occurred in the Takadanobaba subway station of Tokyo and over 20 passengers had uncomfortable symptoms [6]. In the current stage, domestic and foreign scholars mainly conduct diffusion studies for pollution gas or fire smoke in indoor space through numerical simulation and simulation chamber experiments. Both can complete high-precision simulation and analysis with low experimental costs to obtain space-time flow field with high resolution and concentration distribution [7,8]. However, due to the complex design of spatial structure and ventilation system for a large-scale computational domain such as subway station, it is difficult to reconstruct on-site conditions with computational model and simulation chamber, resulting in unpredictable deviation in calculation results [9,10].

To completely understand the gas diffusion rules of a typical subway station under natural ventilation, this paper selects a subway station of Beijing as the target station and SF6 as the tracer gas and firstly conducts a full-scale experimental study on gas diffusion in China. By changing the location of the pollution source, this paper analyzes gas sedimentation, transmission rate, and diffusion range. The results can provide a reference for emergency ventilation and personnel evacuation and lay a data foundation for computer simulation and ventilation.

2 Experimental design

2.1 Overview of subway station and layout of point location

The experiment was conducted at a subway station of Line 15 in Beijing. As shown in Fig. 1, the station is designed with a two-layer underground structure and over 4m net height for each layer, with an overall east-west direction. The east station hall and west station hall at the underground 1st layer are designed with two entrances and exits, with an overall size of public zone 41.3 m * 21.5 m and 44.5 m * 21.5 m, respectively. The underground 2nd layer is designed into a typical island platform of which both ends are connected with escalator and station hall, with size 112.5 m * 14 m.

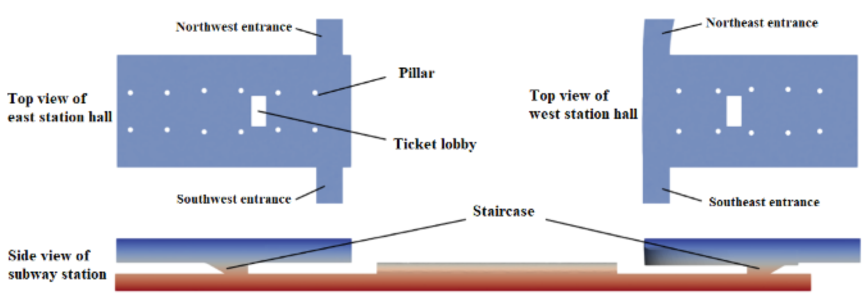


Fig. 1. Construction drawings of the subway station.

As shown in Fig. 2, the gas is released at the west station hall under natural ventilation and total of 15 sampling locations are set in the whole station. Due to different densities, the target gas and air have a large difference in diffusion in the vertical direction, so that the sampling point is optimized at height. The station platform is set with 6 sampling points with a height of 0.5 m and one sampling point with three heights (0.5 m, 1.6 m & 2.5 m); the west station hall is set with 4 sampling points with a height of 1.6 m (height of breathing area) and 4 sampling points with three heights to get relatively complete data of concentration field. The release location S is set at the south 2m of stairway way and the west 1m of S2 stairway entrance. The three-dimensional ultrasonic anemometer (CSAT3B, CampbellScientific Inc.) and 24-channel anemometer (System 6242, Kanomax Japan inc.) are used for monitoring the flow field of the subway station. Fig. 3 shows the layout of point location., where 12 locations are selected for the 24-channel anemometer and 2 monitoring heights(1.6m & 2.5m) are set at each location; a three-dimensional ultrasonic anemometer is uniformly set at the height of 1.6 m to monitor wind speed and direction at a typical area of the station. Each area is monitored for 15 mins.

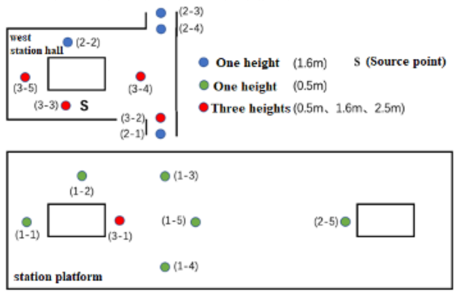


Fig. 2. Location of pollution sources and sampling points.

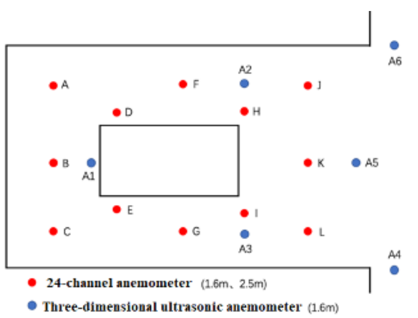
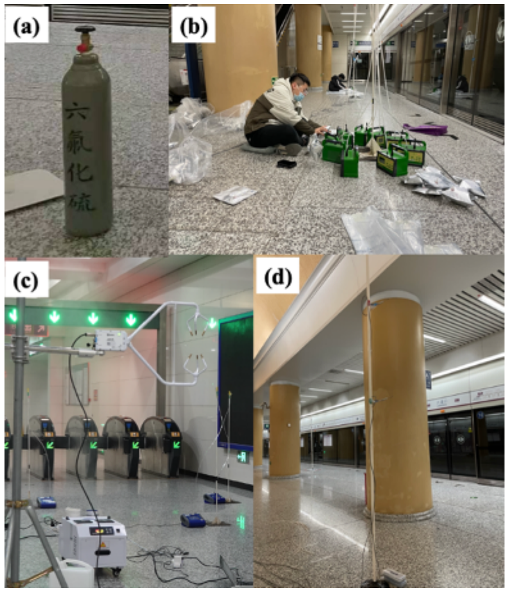


Fig. 3. Location of anemometers.

2.2 Experimental method

Fig. 4 shows on-site pictures. This paper selects SF_6 as the target pollution gas and the cylinder is connected with the wide-mouth bottle via the relief valve to reduce outlet velocity. The release strength is set to 1 kg/min and the release time is 5 min in total. SF_6 is detected with time-sequence acquisition and offline analysis methods. It is sampled at the sampling point every 3 min for 10 times in total. The flow is set to 10 L/min and acquisition volume is 1 L every time. SF_6 is analyzed with Agilent 7860-7000D gas chromatography and mass spectrometer and HP-5MS chromatographic column.



(a) SF6 cylinder (b) Sampling pump and bag(c) Three-dimensional ultrasonic anemometer (d) 24-channel anemometer

Fig. 4. Images of on-site experiment.

3 Results and discussion

Fig. 5 shows wind direction and speed change at Point A1-A6 in the west station under natural ventilation conditions (without train). The results indicate that there is a main flow field in the west station, i.e. the air flows through the stairway exit A1 to the northeast and southeast direction and then exhausts to outside via A2, A6, A3 & A5. The flow field in the north side of the station hall is relatively stable compared to the south side and wind direction is kept at 270±30°, i.e. west-to-east direction. The initial wind speed at the stairway exit A1 is high, over 0.5-1 m/s, and the wind speed at the north entrance and exit is significantly higher than the south entrance and exit.

On the other hand, the uniformly arranged 24-channel anemometer can indicate the overall conditions of the flow field in the area. Fig. 6 shows the monitoring results. The wind speed at A, D, F, H & J on the north side of west station hall is higher than C, E, G, I and L on the south side; the wind speed at the height of 1.6 m in the station hall is commonly higher than the speed at height 2.5 m, so that the pollution gas can diffuse easily at the breathing height.

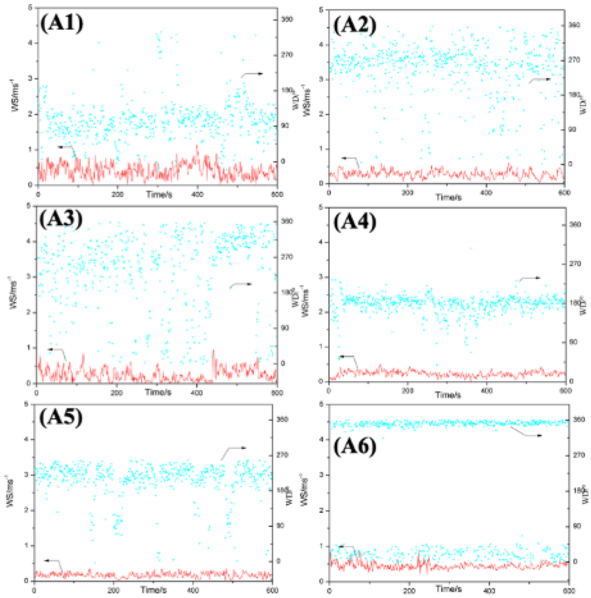


Fig. 5. Wind direction and speed at typical locations of subway station.

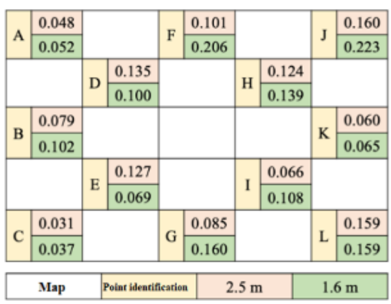
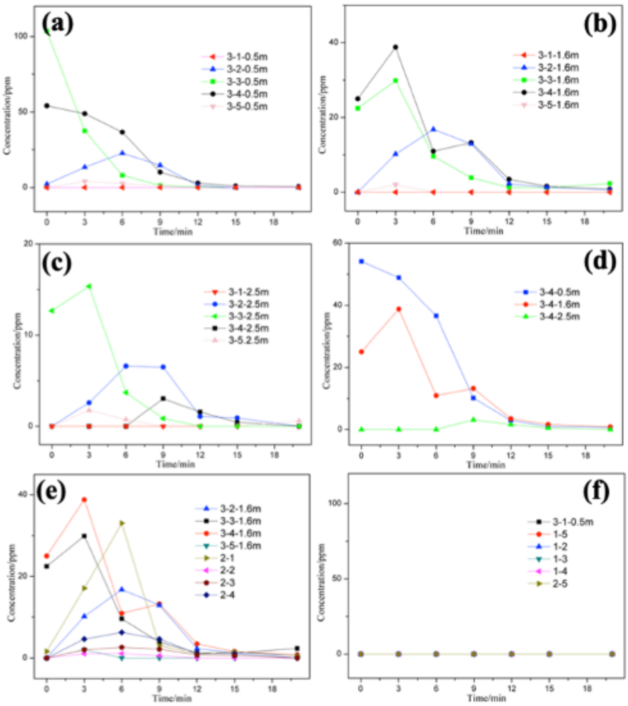


Fig. 6. Wind speed at typical locations of subway station monitored by 24-channel anemometer.

Fig. 7 shows concentration change at each monitoring point when SF6 is released at Point S. The results indicate that the pollution gas is controlled by the main flow field of the west station hall. As shown in Fig. 7(a), due to the influence of density, SF6 deposits at 0.5 m and diffuses fast. The concentration reaches the peak during the 1st sampling (over 5-10 s after release for the moment 0) at sampling point (3-3-0.5m) & (3-4-0.5m) and then decreases slowly. The concentration at entrance and exit (3-2-0.5m) increases gradually and reaches the maximum at 6 min, about 25 ppm. SF6 is not detected during the test at the height (3-1-0.5m) of the station platform. This indicates that heavy gas is released at point S in the station hall and will not result in the transmission of pollutants to the bottom layer. As shown in Fig. 7(b) & 7(c), the concentration decreases gradually with the increase of sampling height at the same location. The (3-4) is taken as an example. The location is close to the release source, where the concentration at height 0.5 m during the 1st sampling is about 55 ppm and then decreases gradually, but reaches the peak within 3 min at the height 1.6m. This indicates that SF6 diffuses at a low level and then transmits to the high level, featured with hysteretic nature, as shown in Fig. 7(d). The overall diffusion path of the pollution gas can be determined based on the sampling at equal altitudes shown in Fig. 7(e) & (f). A high-concentration area can be formed around the point source when the gas is released at Point S. Then the gas will diffuse to the northeast direction along the flow field and spread to the south entrance and exit in the center of the station hall (3-4), and a small amount of gas will flow to the north entrance. The path is consistent with the line of booking tickets and security checks, which may cause personnel injury. The extremely low concentration in the west stairway exit and north side of station hall indicates that only a small amount of SF6 will spread along the path (3-5)-(2-2)-(2-4) so that the path can be used for evacuation. In addition, SF6 is not detected at each point of the station platform. This indicates that the heavy gas will not transmit to the bottom layer.



(a) Sampling at 0.5 m (b) Sampling at 1.6 m (c) Sampling at 2.5 m (d) Sampling at (3-4) with different height (e) Diffusion in station hall (f) Diffusion in station platform

Fig. 7. Concentration of SF6 at typical locations of subway station when release at S.

4 Conclusions

Under natural ventilation, a regular flow field will form in the west station hall, i.e. the airflow enters into the station hall from the entrance of the stairway and then enters into the central area on the east side of the station hall through both the north and south side, respectively. Both airflows converge and then turn back to the north and south entrance and exit, where the airflow in the north side of the station hall is more stable, with a slightly higher wind speed.

If gas leakage occurs at Point S under the effect of the flow field, the gas will flow to the east side of the station hall along the airflow direction and exhaust outside via the south entrance and exit. The path is consistent with the line of booking tickets and security checks, which may cause personnel injury. The pollution gas is not detected in the north channel of the station hall which can be used for evacuation. In addition, SF6 is not detected at each point of the station platform during twice release. This indicates that the heavy gas will not transmit to the bottom layer. During the evacuation, the top fume extractor cannot be enabled to avoid diffusion of pollution gas on the ground to the breathing area and reduce inhalation harm as much as possible.

References

1. Bao Xuding. Current situations, problems and prospect of urban rail transit development in China [J]. China Metros, 2018:10:16-21
2. Cai Hao, Kong Lingjuan, Long Weiding et al. Research on biochemical and radioactive terrorist attack and underground environmental safety [J]. Chinese Journal of Underground Space and Engineering, 2005,1(2):171-191
3. Jonathan S., Markus B., Nils D., Propagation of tracer gas in a subway station controlled by natural Ventilation[J]. Journal of Heat Island Institute International, 2014,9:2-6
4. Hu Yanju, Li Yanhai, Hu Yiwei. Development and application of emergency decision system for unexpected leakage of dangerous chemicals [J]. Journal of Safetyscience and Technology, 2010, 6(4): 109-113
5. Shi Chun, Xu Linjun, Fang Jingjing. Proposal of establishing medical emergency rescue system for unexpected chemical accident and chemical terrorist attack [J]. Journal of Navy Medicine, 2005, 26(2): 111-113
6. Wang Shanshan, Jiang Wei, Xia Zhiqiang. Simple analysis of emergency rescue ability building for nuclear, biological and chemical disaster in Japan [J]. Symposium on The 2nd China Conference on Command and Control, 2014,709-712
7. Tian Xiangliang, Zhong Maohua, Chen Junfeng et al. Full-scale experimental study on cross-transfer station of subway: station hall fire [J]. Journal of Safetyscience and Technology, 2019,15(3):11-18
8. Zhong Maohua, Chen Junfeng, Chen Jiacheng et al. Full-scale experimental study on cross-transfer station of subway: platform fire [J]. Journal of Safetyscience and Technology, 2019, 15(5):42-48
9. Andreas P, Markus B, Julia R, et al. OrGaMIR-Development of a safety system for reaction to an event with emission of hazardous airborne substances-like a terrorist attack or fire-based on subway climatology[J]. 4th International Symposium on Tunnel Safety and Security, 2010, 451-462
10. Markus B, James C, Andreas P. Coupling tracer gas experiments with evacuation simulation: An empirical approach to assess the effectiveness of evacuation routes in subway stations[J]. 6th International Symposium on Tunnel Safety and Security, 2014, 505-512