Analysis of factors affecting vent system for underground gas storage

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Abstract: The operating conditions of vent system for underground gas storage was introduced. The numerical simulation of the diffusion process of natural gas was conducted using process hazard analysis software tool (PHAST) with gas release velocity greater than 40 000 m^3/h. The effects of release velocity, atmospheric stability and wind speed on the diffusion area, flash fire, explosion and spray fire of natural gas were analyzed. The results show that the higher release velocity is, the bigger explosive area is; the stabler atmosphere is, the less natural gas diffuses; the lower wind speed is, the less natural gas diffuses, and the lower diffusion speed is, the bigger dangerous area is. Moreover, wind speed also has an effect on flash fire and heat radiation. In order to ensure safety of vent process of natural gas storage, the release velocity should be controlled and atmospheric conditions should be considered at the same time.

Key words: gas diffusion; release velocity; explosive area; atmospheric stability

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Natural gas is important high quality energy, but now there is an imbalance between supply and demand of natural gas. Therefore, the construction of underground gas storage is essential for each country considering the peak demand and emergence reserve of natural gas.

Due to powerful underground gas storage pressure and harsh vent conditions, fire separation should be determined based on radiant heat intensity calculations of people, equipment and architectural structures. Fire separation can refer to requirements of gas pipeline station with release velocity less than 40 000 m^3/h. But the combustible gas diffusion process with release velocity greater than 40 000 m^3/h needs to be studied quantitatively[1]. The fire separation can be eventually determined by 50% of explosive limit range, radiant heat diffusion area and the effect area of explosion concentration. The numerical simulation of the diffusion process of natural gas was carried out using process hazard analysis software tool (PHAST) with release velocity greater than 40 000 m^3/h, and the effects of release velocity, atmospheric stability and wind speed on diffusion range, flash fire, explosion and spray fire of natural gas were analyzed.

1 Analysis of factors affecting vent system

Underground gas storage is an important part of natural gas storage and transportation system. Generally, underground natural gas can be stored in depleted storage, aquifer, salt caves and abandoned mine[2]. In China, the gas storage is divided into dry gas storage type and salt cavity type. Dry gas storage utilizes a reservoir under the ground with the depth of 2000 m. It has the characteristics of high formation pressure, less investment, quick results and short payback period, therefore, nearly 80% of gas storage uses this type. While gas storage in salt caves has relatively small capacity and low formation pressure, therefore, it is suitable for daily or weekly reg-

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ulating peak gas storage with high-sensitivity peak shaving and strong adaptability to gas fluctuation. Underground gas storage is mainly responsible for peak shaving of long distance natural gas pipeline. The vent system for gas storage has multiple ground facilities, large device scale, complicated temperament during the injection-production cycle, high stress level, and high and low pressure systems. The initial release pressure is high in high pressure system . Instantaneous release capacity is greater than average release capacity. The pressure difference is large before and after release, and the gas temperature is low after release.

If the pressure of facility and system exceeds design pressure in an accident condition, safe release is taken to prevent the expansion of the accident. Manual pressure release is implanted during the repair and maintenance of devices[3]. The scale of vent system is determined by release velocity. According to different operating conditions of injection-production gas and the size of vent pipe and vent tube (torch), related supporting facilities are determined. The fire separation of vent riser area depends on gas diffusion area and the calculation of radiation.

2 Natural gas diffusion model

Natural gas is a type of multi-component gas mixture consisting of alkane and its explosion limit is 5% −15%. Since 1960s, foreign scholars have studied the release and diffusion of dangerous gas theoretically and experimentally. Many calculation models have been proposed to simulate gas release and diffusion processes, such as Gauss model[4], building model (BM)[5], (3D finite element model (FEM3) [6], three-dimension model[7], unified dispersion model (UDM) [8] etc. Among them, Gauss model is only applicable to neutral gas; BM, FEM3 and three-dimension model only can be applied to heavy gas diffusion; and UDM can be used for any release process.

PHAST software is specially used for hazard analysis and secure calculations of oil, petrochemical and natural gas[6]. It can simulate possible events occurring when gas is initially released to long-distance dispersal, and can offer the formation, evaporation, flash fire and toxicity hazard models of liquid pool. PHAST software uses UDM to describe the processes and effects of gas release and diffusion. The simulation results are close to real-world scenes.

3 Simulation

3.1 Effect of release velocity on natural gas diffusion area

Based on determined benchmark conditions, the effect trend of gas release velocity on diffusion is analyzed according to different diffusion simulation results derived from different gas release velocities that are changed where the gas release velocity is greater than 4×10^4 m^3/h. The initial gas venting pressure is 10 MPa, initial gas vent temperature is 25 ℃, gas venting component is methane and the atmospheric stability is *D*.

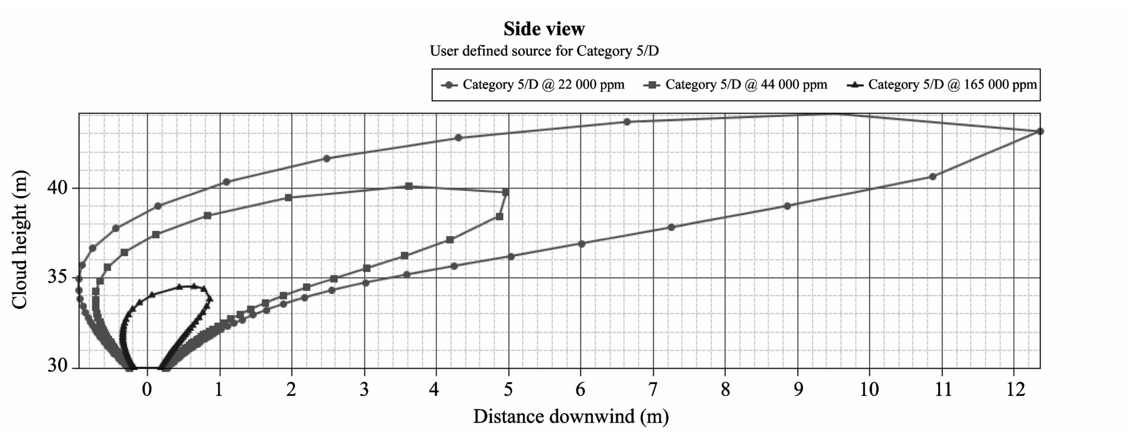

Fig. 1 Diffusion area with release velocity of 5×10^4 m^3/h

Figs. 1−3 show the side views of natural gas diffusion areas with different gas release velocities.

Horizontal direction represents horizontal distance formed by a certain concentration of natural gas gathering in diffusion process downwind. Vertical direction refers to the height of space formed by natural gas within a certain horizontal distance. Three outlines represent the diffusion area of different concentrations of natural gas, furthermore, a safe distance is determined.

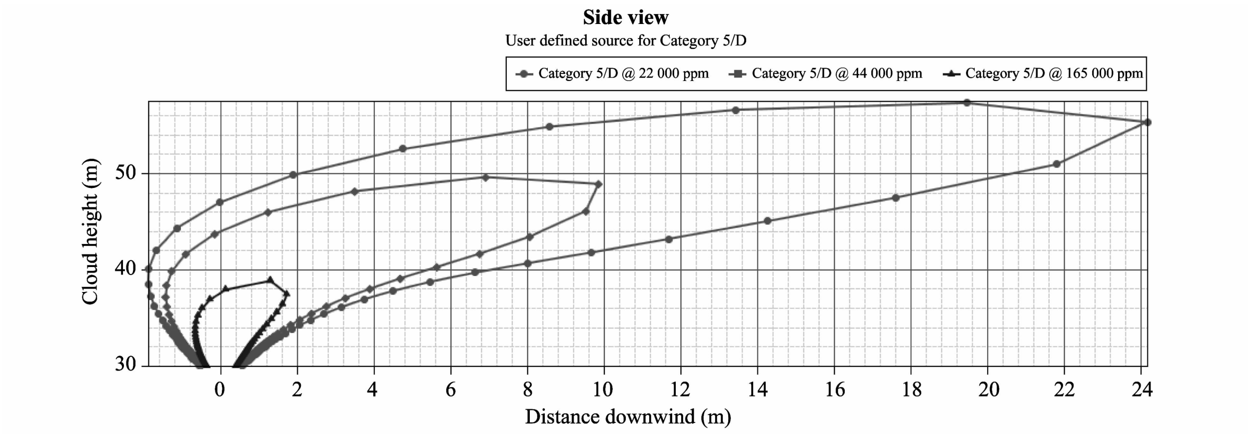

Fig. 2 Diffusion area with release velocity of 20×10^4 m^3/h

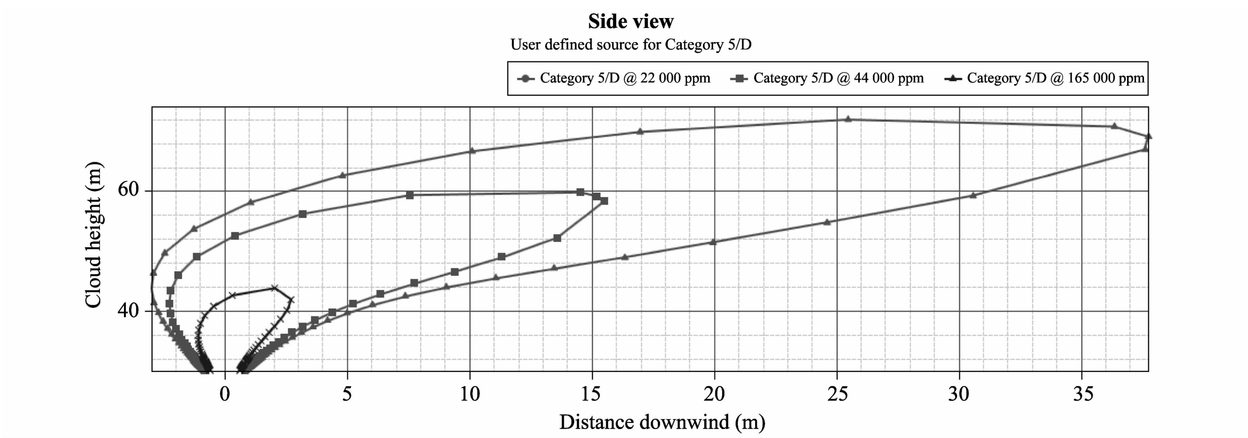

Fig. 3 Diffusion area with release velocity of 50×10^4 m^3/h

Table 1 shows the calculation results of effect of release velocity on diffusion area.

Table 1 Calculation results of effect of release velocity on diffusion area

Release velocity ($\times10^4$, m^3/h)	16.5% CH_4 (m)	4.4% CH_4 (m)	2.2% CH_4 (m)
5	0.86	5.0	8
20	1.7	9.80	24.5
50	2.7	15.4	37.9

Note: Methane explosion limit is 5%—15% in air. The concentration index of diffusion area by simulation is 4.4%—16.5%. Methane concentration of 2.2% is the range of possible flash fire.

As seen from Table 1, there is a close relationship between diffusion area and release velocity of natural gas. With the increase of release velocity, natural gas diffusion area and explosion area also increase gradually, but the rate of increase is a little. When release velocity is less than 50×10^4 m^3/h, the area outside of 40 m is safe. According to Ref. [9], the fire separation and vent pipe should be arranged in higher ground. The space between vent pipe and gas station should not be less than 10 m if the release velocity is less than 1.2×10^4 m^3/h; while the space between vent pipe and gas station should not be less than 40 m if the release velocity is greater than 1.2×10^4 m^3/h or less than 4×10^4 m^3/h.

3.2 Effect of atmospheric stability on vent system

Based on the benchmark conditions, with release velocity of 50×10^4 m^3/h, by changing atmospheric stability, the effects of atmospheric stability on diffusion area, flash fire, explosion and spray fire of natural gas are analyzed by simulation.

Figs. 4—7 represent the diffusion area of natural gas with concentration index greater than 2.2×10^{-2} in different atmospheric stability cases (A-F) with the wind speed of 5 m/s and release velocity of 50×10^{4} m^3/h. As seen from Figs. 4 and 5, when the atmospheric stability changes from scale A to scale F, the flash fire range increases gradually. The stabler atmosphere is, the less natural gas diffuses, the bigger explosion area is, and the bigger dangerous area is. As seen from Figs. 6 and 7, atmospheric stability has little effect on explosive area and Jet flame radiation range.

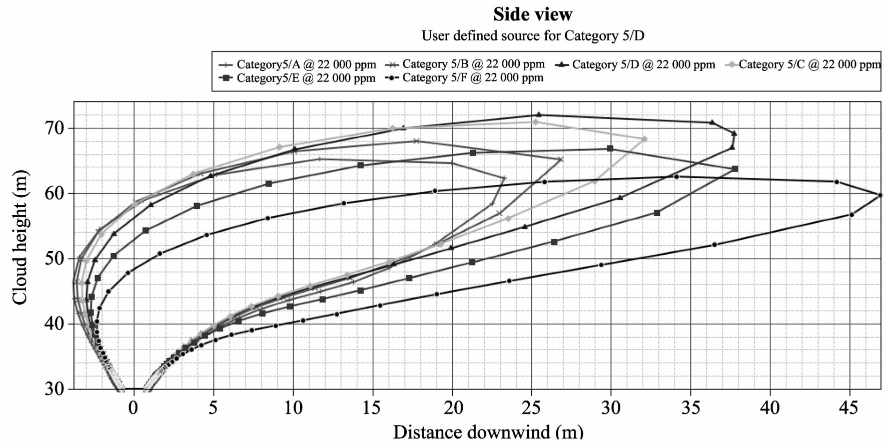

Fig. 4 Effect of atmospheric stability on diffusion area

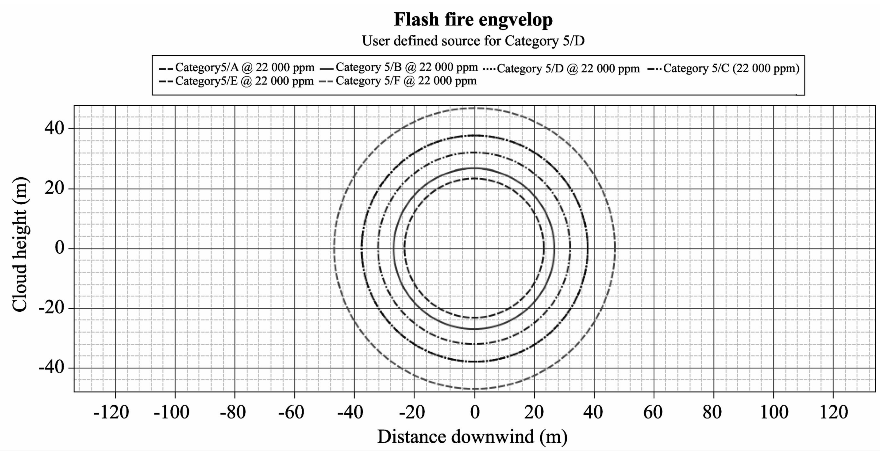

Fig. 5 Effect of atmospheric stability on flash fire range

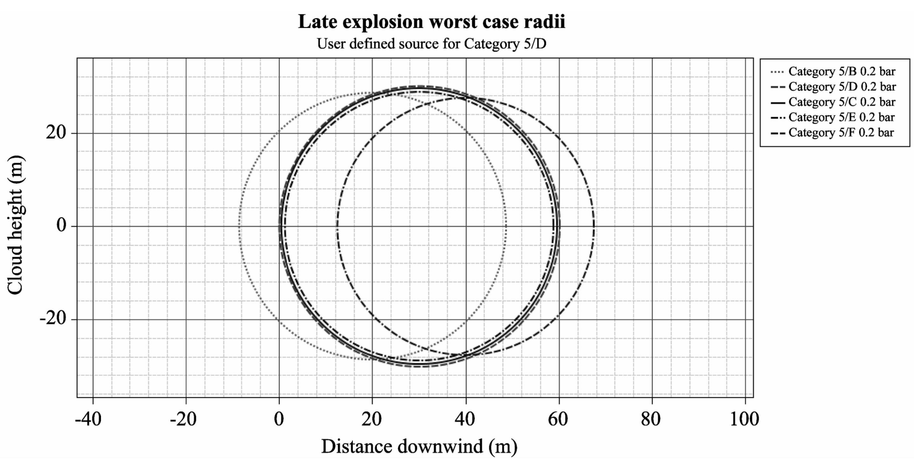

Fig. 6 Effect of atmospheric stability on explosive area

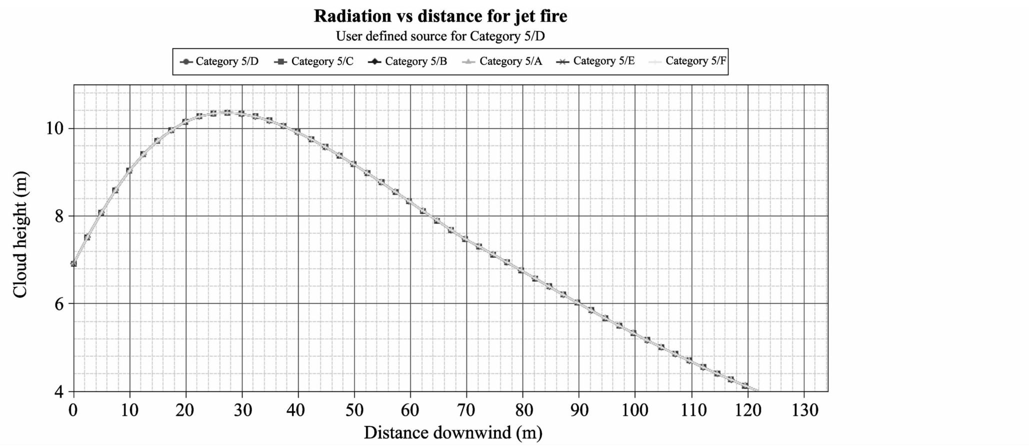

Fig. 7 Effect of atmospheric stability on Jet flame radiation range

3. 3 Effect of wind speed on vent system

Based on the benchmark conditions, by changing wind speed, the effects of wind speed on diffusion area, flash fire, explosion and spray fire of natural gas are analyzed by simulation.

Figs. 8-10 represent the diffusion area of natural gas with concentration index greater than 2.2×10^{-2} in different wind speed cases (A-F) with atmospheric stability of scale D and release velocity of 50×10^{4} m^3/h. In Fig. 8, when the atmospheric stability changes from 1—20 m/s, the explosive clouds formed by discharge of natural gas change greatly. The thickness of clouds reduces gradually and stretches in downwind direction. In Fig. 9, with the increase of wind speed, flash fire range increases with small rate. While in Fig. 10, with the increase of wind speed, both jet fire radiation intensity and explosive area increase gradually. Wind speed has a great effect on jet flame radiation range.

The lower wind speed is, the greater natural gas diffuses, stretching in downwind direction. With the increase of wind speed, the gas concentration in downwind direction reduces gradually. High wind speed is conducive to the diffusion of natural gas. While the lower wind speed is, the bigger the dangerous area is. The reason is that the wind speed aggravates the advection of gas clouds. The quicker wind speed is, the more significant transport effect is. Therefore, the natural gas concentration in downwind direction decreases. Besides, with the increase of wind speed, the fluctuating velocity increases, which enlarges gas turbulence and results in diluted gas. At the same time, the increase of gas turbulence makes the heat exchange of clouds with surrounding environment become violent, cold gas temperature rise rapidly and density decrease. Thus, natural gas concentration declines and damage is reduced.

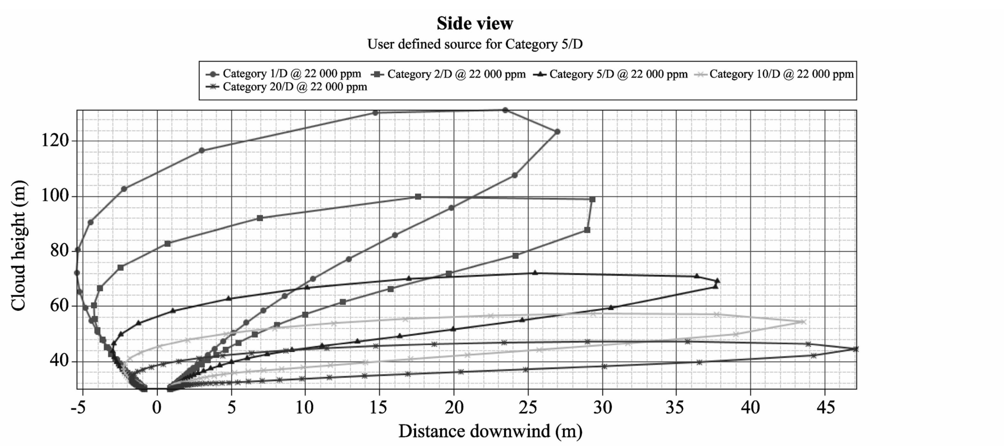

Fig. 8 Effect of wind speed on diffusion area

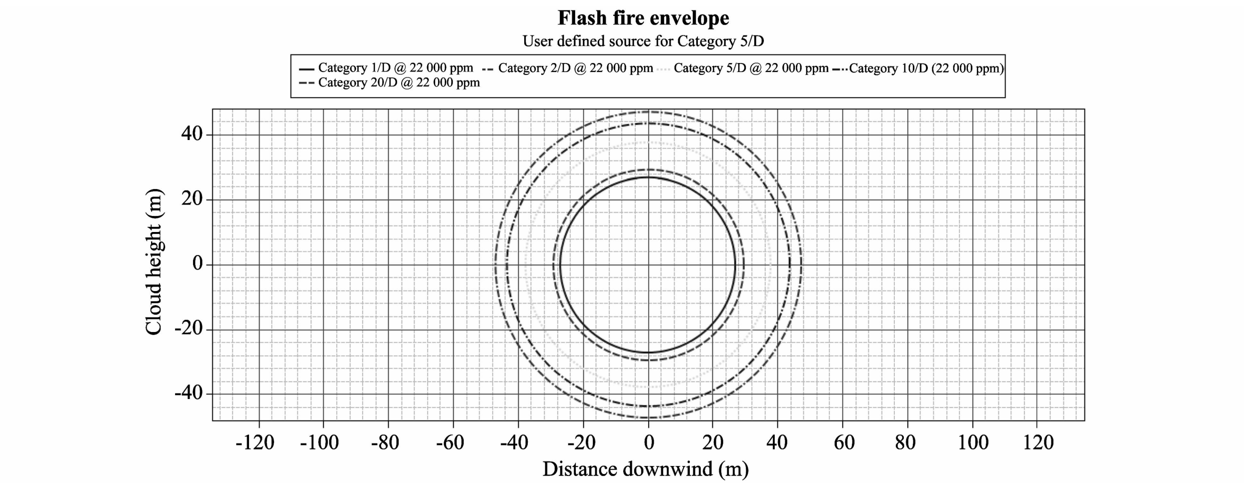

Fig. 9 Effect of wind speed on flash fire range

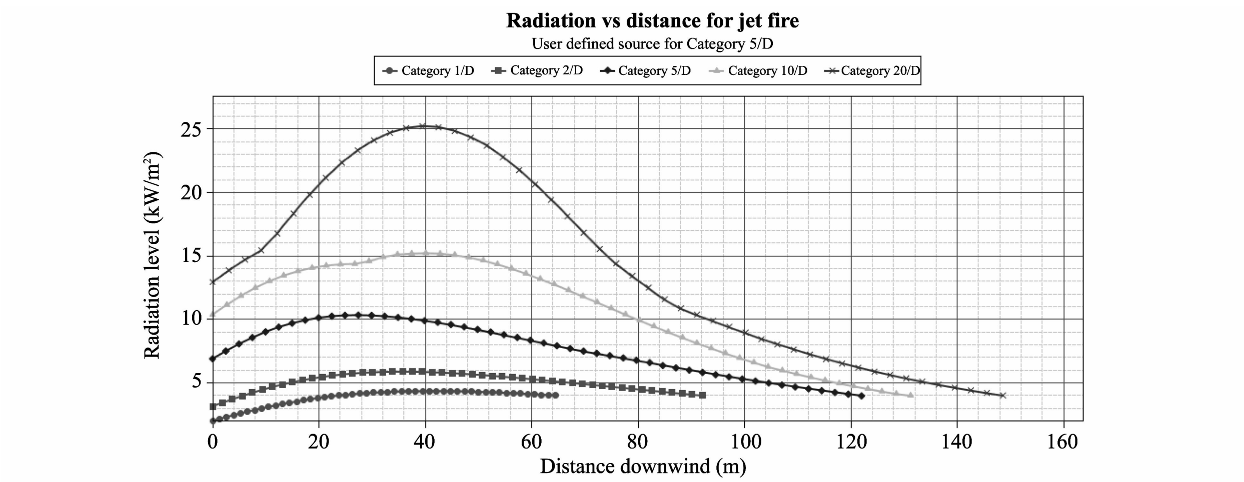

Fig. 10 Effect of wind speed on Jet flame radiation range

4 Conclusion

1) PHAST soft is adopted to simulate the explosive area generated by natural gas diffusion at different release velocities. By comparing the simulation results, it can be concluded that the higher release velocity is, the the larger explosive area of inflammable gas becomes. Meanwhile, considering the effect of noise on surrounding environment, the release velocity should be limited and the atmospheric valve should be turned on gradually to control temperature and noise before release.

2) The wind speed and atmospheric stability of vent system are calculated. It indicates that the wind speed aggravated the advection of gas clouds, which has the significant effect on gas diffusion. The wind speed also enlarges the gas turbulence and makes it easy for gas to be diluted. Therefore, high wind speed contributes to gas diffusion. The effect of atmospheric stability on gas diffusion is presented in horizontal direction. The stabler atmospheric stability is, the larger explosive area becomes.

3) By analyzing the effects of release velocity, atmospheric stability and wind speed on diffusion area, the fire separation distance of vent system for gas storage is determined. Advanced automation control technology at home and abroad is used for automatic turn-off and vent of equipment. By calculating the amount of gas of multi-input multi-output junction and underground gas storage, it can be regulated by vent system.

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储气库放空系统影响因素分析

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摘　要： 本文介绍了储气库放空系统工况，运用 PHAST 软件对放空速率大于 4×104 m3/h 的天然气扩散过程进行了定量模拟，研究了放空速率、大气稳定度和风速对天然气扩散范围、闪火、爆炸和喷射火的影响。研究表明：放空速率越大，可燃气体爆炸范围越大；大气稳定度越高，天然气扩散越慢；风速越小，天然气扩散越慢；天然气扩散越慢，危险区域越大；同时，风速对闪火和辐射强度也有一定的影响。因此，在放空时应限制放空速率，同时要考虑环境因素对扩散的影响，以确保气库安全。

关键词： 天然气扩散；放空速率；易燃易爆区域；大气稳定度

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