Simulation of pressure tank leakage based on PHAST

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Abstract: Chemical plants usually store hazardous chemicals in high-pressure or low-pressure storage tanks in the form of pressurization, liquefaction, and low temperature. The poisonous gas in the tank is easily diffused. If a leakage accident occurs, it will cause personal injury and environmental pollution. In this paper, based on the propane acrylonitrile project in an industrial park, major hazard identifications were identified for the tank area (risk level is Level 1), then PHAST software was used to simulate the leakage and diffusion of acrylonitrile storage tanks. It was concluded that the greater the wind speed, the leakage pore and the more stable atmosphere, the greater the leakage and diffusion of hazardous areas. And timely and intuitive prediction of the diffusion process and scope of toxic gases provide a scientific reference for taking corresponding countermeasures and on-site control after the accident.

Introductions
Recently, with the rapid development of the production scale of chemical companies, the number of hazardous chemicals varieties and the demands has increased sharply. Most of chemicals are often inflammable, explosive, and toxic. If during the process of production, usage and storage, with improper management or disoperation, large-scale leakage of hazardous chemicals may result in catastrophic consequences [1,2].

Up to now, some scholars at home and abroad have studied the hazardous chemicals leakage diffusion models, which mainly include theoretical analysis, experimental research and practical application. Hundreds of typical accident consequence models have been put forward, such as Gaussian model, BM model, Sutton model, FEM3 model and P-G model[3-7], and two-phase boundary flow leakage model[8-9]. Combined with different leakage consequences models, related software, with common applications, such as PHAST, SAFETI, and ALOHA software, have been developed to simulate different hazardous chemicals.

1. Project situation

1.1 Production introduction
The project is located in an industrial park as a subproject of a 12 million tons crude oil processing project. The total area is 45,000 square meters, and its layout is shown in Figure 1. There are no large rivers in the area and the rivers have short runoff. The amount of submerged bedrock fissure water and sedimentary alluvial pores is limited. The tank area is mainly stored in vertical cylindrical tanks. The project storage tank is divided into product storage tank area and automobile loading and unloading area. The product area has 2 hydrocyanic acid storage tanks, 4 acrylonitrile storage tanks and 2 acetonitrile storage tanks.
1.2 Major hazard identification results in store system
Based on the above analysis results, the major hazard level of hazardous chemicals in the storage tank area is Level I. The PHAST software simulation was used to carry out safety assessment of the storage tank area, which is benefit for the safety production. Due to the limitations of the conditions, only the simulation analysis of the consequences of the leakage accident in the acrylonitrile storage tank area.

2. Leakage simulation based on PHAST software
2.1 Parameter setting
The simulated accident scenario was as follows, the acrylonitrile storage tank was damaged by perforation of the cylinder, and the hole was generated at a height of 4 meters, forming a liquid pool, which resulted in continuous evaporation and diffusion. Assume that the spill is effectively controlled within 20 minutes.

(1) Set meteorological conditions.
Assume that the surrounding atmosphere was 1.5/F, 3/F, 5/F, 1.5/D
(2) Set weather data
Assume that the average summer temperature in the region was 28.1°C, the relative humidity is 70%, and the surface temperature for diffusion calculation is 30.7°C.
(3) Set topographic condition
The ground roughness in PHAST is specified as "30mm, open flat grass, a small number of isolated objects". This type of surface was chosen because it produced a conservative estimate of the downwind distance and reduced the estimate of excessive wind distance. Release position 7m above sea level. The height of the cofferdam is 0.4m.
(4) Leakage source parameters
Leakage source height was 4m. Type of leak belonged to continuous leak. Leakage times were 20min.
(5) Model setting
For the 5000m³ acrylonitrile storage tank, whose filling factor is 71%, the maximum allowable working pressure is 111.4kPa in the tank, the density of acrylonitrile liquid is 0.8004kg/m³, the density in the gaseous state is 1.830kg/m³ and the diameter of the tank is 23.7m. The height of the tank body is 12.53m. Holes with a leakage equivalent diameter of 7 mm (small hole leakage), 25 mm (mid hole leakage), and 50 mm (large hole leakage) are respectively targeted.
(6) Concentration setting
In the risk prediction process, it is necessary to make a reasonable choice of the hazard boundary (or standard). PHAST defines several concentration related to the action time, and selects the ERPG (Emergency Response Plan Guide) designated by the American Industrial Hygiene Association as the downwind distance. The basis of the concentration line, because in real life, ERPG-3 has a more realistic effect, it stipulates the highest toxic gas concentration value in the atmospheric environment, and in the environment below this concentration standard for 1h, most people will not be affected. Life threats can eventually take refuge. The acrylonitrile ERPG concentration is divided into three levels, the specific parameters are shown in Table 1.

| Parameters | concentration (ppm) | concentration (mg/m³) | Action time (s) |
|------------|---------------------|-----------------------|-----------------|
| ERPG-1     | 10                  | 21.7                  | 3600            |
| ERPG-2     | 35                  | 75.96                 | 3600            |
| ERPG-3     | 75                  | 162.76                | 3600            |

(7) Risk consequence analysis
For low-pressure normal temperature liquid storage tanks, flashing does not occur after the leak, and the leaked liquid will form a liquid pool on the ground, and the size of the liquid pool increases with time when the boundary is not reached. The liquid pool is mainly based on mass evaporation.
After evaporation, it rapidly diffuses in the form of gas. The mass evaporation rate increases with the increase of the liquid pool area. After the liquid flows to the boundary, the liquid pool area no longer increases, and the mass evaporation rate does not increase.

According to the Emergency Response Plan guidelines, the potential death zone we are most concerned with is the area of acrylonitrile concentration above 75ppm. The next area of concern is acrylonitrile above 35ppm, which can cause adverse effects on the human body. The last area of concern is acrylonitrile above 10ppm, which has a transient adverse effect on the human body.

2.2 Simulation results

2.2.1 Different wind speed effect on the simulation. Figure 1 shows that a top view of the leakage diffusion range at different wind speeds. In the simulation, the three curves represent the diffusion boundary range of leakage at three different wind speeds. Under the condition that the atmospheric stability is F, the solid blue line represents the diffusion range at a wind speed of 1.5 m/s, the green long dash represents the diffusion range at a wind speed of 3.0 m/s, and the red dotted line represents a wind speed of 5.0 m/s. The range of diffusion shows that the greater the wind speed, the smaller the danger zone. Conversely, the smaller the wind speeds, the larger the danger zone.

![Cloud Footprint](image)

**Figure 1** 7mm hole leakage diffusion range top view

2.2.2 Different leakage holes’ diameters effect on the simulation. As shown in Figure 2, Figure 3, and Figure 4, the solid blue line represents ERPG-1 (10ppm), the green long dashed line represents ERPG-2 (35ppm), and the red dotted line represents ERPG-3 (75ppm). 7mm hole leakage ERPG-1 concentration downwind distance is about 1736m, cloud group maximum single side width 103m; 25mm hole leakage ERPG-1 concentration downwind distance is about 7297m, cloud group maximum single side width 408m; 100mm hole leakage ERPG-1 concentration downwind distance is about 21925m, and the largest single side width of the cloud is 2,427m. It can be seen that the size of the aperture affects the amount of leakage, so in the case of the same weather conditions, the larger the aperture, the larger the dangerous area.

2.2.3 Different atmospheric stabilities effect on the simulation. As shown in Fig. 6, the hole with a diameter of 7 mm is at a wind speed of 1.5 m/s and the atmospheric stability is F and D, respectively (blue solid line represents 1.5/F, green dotted line represents 1.5/D), atmosphere The cloud area when the stability is F is significantly larger than the cloud area when the atmospheric stability is D.
Figure 2 Top view of 7mm hole leakage diffusion range in atmospheric environment 1.5/F

Figure 3 Top view of leakage diffusion range of 25mm hole in atmospheric environment 1.5/F

Figure 4 Top view of the 50mm hole leakage diffusion range in the atmospheric environment 1.5/F
3 Conclusions
(1) For the leakage source of the same aperture, the larger the wind speed, the more volatile the gas will diffuse; when the wind speed is low, the gas will be slower due to the turbulence of the atmosphere, and the dangerous area will be larger.

(2) Under the wind speed of 1.5/F in summer, the 10ppm acrylonitrile concentration zone will affect the sewage pretreatment plant, loading and unloading zone and foam station, and exceed the boundary of the plant area in the south and west. Among them, under the influence of the dominant wind direction (southwest wind), the storage tank area and the foam station will be in concentration, but will not affect the hydrocyanic acid and acetonitrile storage tank areas. From the GIS map of concentration, it can be seen that after an accident, the evacuation along both sides of the cross wind can escape the accident-contaminated area in the shortest time.

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Reference
[1] Sun Tianshu. Research of Environmental Risk Assessment of Sudden Typical Accident for Storage Tanks of Dangerous Chemicals [D]. Dalian: Dalian University of Technology, 2013.05.
[2] Yuan lizhi. Comparison and analysis on the research situation of release and dispersion models of hazardous chemicals at home and abroad[J]. China Safety Science Journal, 2011,21(01):37-42.
[3] Ding Xinwei, Wang Shulan, Xu Guoqing. A Review of Studies on the Discharging Dispersion of Flammable and Toxic Gas [J]. Chemical Industry and Engineering, 1999(02):58-62.
[4] Zhou bo, Zhang guoshu. Numerical simulation for the leakage diffusion of harmful materials[J]. Industrial Safety and Dust Control, 2005(10):42-44.
[5] Liu Zhao, Ouyang Kun. The Applied Research of Gaussian Puff Model Based on 3D GIS and TGIS[J]. Bulletin of Surveying and Mapping, 2011(05):80-82+88.
[6] Li Shiwèi, Wang Jiáqiáng. Improved Gaussian estimate model algorithm for radioactive gas diffusion [J]. Application Research of Computers, 2012,29(01):123-126.
[7] Lin Yipping. An application in environmental protection system based on integration of Temporal-Gis and atmospheric dispersion model of toxic chemical [D]. Shanghai Jiao Tong University, 2009.
[8] Dong Suifang, Li Zhuxia. Analysis and application for PHAST in LPG storage condition [J] Journal of Safety Science and Technology, 2007,3(4):87-90.

[9] Cao Bin, Liu Fuzhi, Li Qi. Research and Analysis of Purification and Gas Diffusion and Diffusion Based on PHAST Software [J].West-china Exploration Engineering, 2011,23(10):75-77.