Numerical simulation analysis of leakage gas cloud explosion in LPG tank farm

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Abstract: a LPG tank farm model was established by FLACS software to simulate the leaking gas cloud explosion. The propagation process of explosion flame and the change process of explosion overpressure field and temperature field were studied under the influences of different leakage rate, wind speed and wind direction. The results show that, the larger the leakage rate is, the larger the impact area of gas cloud explosion is, the higher the explosion overpressure and temperature are. When the wind speed is larger than 4 m/s, the higher the wind speed, the faster the heavy gas will be diluted by the ambient gas, and the explosion will be suppressed. Under the influence of different wind directions, the impact area of explosion is also different.

1. Introduction
With the continuous development of the chemical industry, the application of liquefied petroleum gas (LPG) in production and life is more and more widely, and the safety problems also follow. In order to prevent and control LPG leakage and explosion accidents, scholars at home and abroad have done a lot of research in theory, experiment and simulation, and achieved rich research results. At present, the theoretical models of gas diffusion include FEM3 model, Sutton model, BM model, Gaussian model [1-4], which are widely used. TNO multi energy model and TNT model are used to calculate the shock wave of vapor cloud explosion [5-8]. In the aspect of experiment, scholars have carried out experimental research on the combustion and explosion characteristic parameters of LPG. Luo et al. [9] and Zhou et al. [10] have measured the effects of different volume fractions of N₂ and CO₂ on the explosion limit and pressure parameters of LPG. Shao et al. [11] analyzed the ignition energy of LPG and the propagation law of flame after explosion by using the self-designed test device, and concluded that the relationship between ignition energy and volume of LPG is in a gentle state within 5% - 9%, and outside this range, the ignition energy will change greatly when the volume fraction changes slightly. In addition, large-scale experiments were carried out to study gas leakage, diffusion and combustion. Lawrence Livemore national laboratory conducted burro test [12] and coyote test [13] respectively to study the diffusion and combustion characteristics of vapor cloud on water surface after LNG overflow. Xing et al. [14-15] respectively studied the internal temperature response of LPG storage tank in pool fire environment and jet flame environment through experiments, and considered that jet flame is more dangerous than pool fire. In the aspect of numerical simulation, Kartal [16] used
FLUENT to simulate the internal pressure and deformation of small LPG storage tank explosion, and carried out failure analysis. Zhai et al. [17] simulated the change of LPG diffusion process and the influence on the explosion risk area formed by different shapes of leakage holes. Li et al. [18] simulated the consequences of large LNG storage tank leakage accident based on MATLAB, and the results showed that the diffusion range of vapor cloud increased with the increase of the height of leakage point after LNG leakage.

In this paper, based on the actual working conditions and the layout of the tank farm, FLACS is used to model the large LPG spherical tank farm. Combined with the dangerous vapor cloud generated in the leakage process, the location of the ignition source is selected according to the actual situation to simulate the LPG leakage explosion accident, and the influence of leakage rate, wind speed and wind direction on the gas cloud explosion is studied. It has certain practical significance and scientific research reference value for LPG production and storage industry, and has guiding significance for fire rescue personnel to make reasonable rescue plan.

2. Modeling

2.1. geometric model
The simulation object of this paper is a LPG spherical tank farm in an industrial park in Shaanxi Province. There are eight LPG spherical steel tanks in the farm, and the volume of each spherical tank is 1000 m³. The simulation area is the whole LPG tank area (X: 0-90, Y: 0-130, Z: 0-40), and its geometric model is shown in Fig.1, the leakage hole is set at the bottom of No. 1 tank, with an area of 0.015 m², a position height of 1.3 m (coordinates: 58.6, 87.4, 1.3). The ignition source is located in the workshop in the west of the tank farm (55 m, 106.5 m, 0.6 m), as shown in Fig.2. It is assumed that the electrical spark or open fire will be the ignition source.

2.2. Working conditions
Initial conditions: ambient temperature is 25 °C, atmospheric pressure is 1 atm, ground roughness is 0.01 m, atmospheric stability grade is F. The composition of LPG was determined and simplified to 28.59 % propane, 70 % butane and 1.41 % pentane.

The direction of gas leakage is vertical (- z); the leakage velocity is 8 kg/s, 12 kg/s and 16 kg/s; according to the local wind speed frequency in recent five years, no wind, 2 m/s, 4 m/s and 6 m/s are set; the wind direction is set as north wind (- x), east wind (y) and northeast wind (- x + y).
Tab.1 Initial conditions of LPG tank leakage

| Number | Leakage rate / kg/s | Wind speed / m/s | Wind direction |
|--------|---------------------|------------------|----------------|
| 1      | 8                   |                  | X-Y            |
| 2      | 12                  | 2                | X+Y            |
| 3      | 16                  |                  | X+Y            |
| 4      | 0                   |                  |                |
| 5      | 4                   | 2                | X+Y            |
| 6      | 4                   |                  | X+Y            |
| 7      | 4                   |                  | X+Y            |
| 8      | 4                   | 4                | Y              |
| 9      |                     |                  | X+Y            |

3. Numerical simulation of leakage gas cloud explosion in LPG Tank Farm
When the storage tank leaks, the coverage and diffusion direction of combustible gas cloud are affected by many factors, including leakage speed, leakage direction, wind speed, wind direction and obstacles. The location of ignition point plays a key role in whether the gas cloud can explode. According to the actual situation of the tank farm, the location of the maximum frequency of fire source is set as the ignition point. The situation of gas cloud explosion under different leakage speed, wind speed and wind direction was analyzed.

3.1. Influence of leakage rate on gas cloud explosion
When the wind speed is 2 m/s and the wind direction is northeast (- x + y), the influence of different leakage rates on the flame propagation process after the leaking LPG gas cloud explosion is shown in Fig.3.

Fig.3 Change of PROD over time at different leakage rates
It can be seen from Fig.3 that when the LPG storage tank leaks and the gas cloud leaks and explodes, a fireball is formed at the ignition source at first, and then it spreads rapidly from the factory building to the tank farm, and at the same time it spreads rapidly to the sky, and the fire surrounds the storage tank No.1. With the increase of leakage speed, the larger the area of combustible gas cloud, and the larger the explosion impact area. This is because under the same other conditions, the greater the leakage rate, the greater the quality of the leaked LPG, and the greater the area covered by the combustible gas cloud. After an explosion occurs, the greater its impact.

When the spherical storage tank leaks, the overpressure and temperature changes on the surface of No.1 storage tank are shown in Fig.4 when the gas cloud formed under different leakage velocities explodes.

![Overpressure and temperature changes on tank surface under different leakage rates](image)

Fig.4 Overpressure and temperature changes on tank surface under different leakage rates

It can be seen from Fig.4 (a) that when the gas cloud leaked from LPG storage tank encounters fire source and explodes, the explosion overpressure reaches the peak rapidly, and then decreases rapidly. With the increase of leakage speed, the peak pressure value gradually increases, and the peak pressure is 0.0573 bar when the leakage speed is up to 16 kg/s. As can be seen from Fig.4 (b), when the gas cloud explodes, the temperature of the tank farm increases rapidly to the peak value, which is 2220 K, 2268 K and 2269 K, respectively, and then remains around the peak value, and finally shows a downward trend and returns to the normal temperature state. With the increase of the leakage rate, the earlier the temperature rises, the longer the duration of the peak value.

### 3.2 Influence of wind speed on gas cloud explosion

When the wind direction is northeast (- x + y) and the leakage speed is 4 kg/s, under different wind speeds, the propagation process of temperature field after gas cloud explosion is shown in Fig.5.
It can be seen from Fig.5 that when the combustible gas cloud explodes, the temperature changes the earliest at the ignition source position, and then diffuses around. With the explosion continuing, the temperature increases rapidly, and the influence range of high temperature increases rapidly. The temperature in the central area is the highest, and the surrounding temperature is the lowest. The area with temperature greater than 2000 K accounts for more than half of the high temperature area. The maximum temperature and the impact area of high temperature first increases, and then decreases. When the wind speed is 2 m/s, the impact area is the largest, and the temperature is the highest, the maximum temperature is 2500 K. The wind flow promotes the diffusion of the gas cloud, it accelerates the diffusion of the gas cloud. When the wind speed is 4 m/s, the diffusion area of the gas cloud is larger, and the area of the gas cloud within the explosion limit range becomes smaller, therefore, the impact area becomes smaller and the temperature decreases.

When the leakage direction is -Z, the wind speed is 2m/s, and the wind direction is northeast wind (-X+Y), when the gas cloud formed at different wind speeds explode, the overpressure and temperature changes on the surface of the No.1 storage tank are shown in Fig.6.
It can be seen from Fig. 6 (a) that when the gas cloud after the tank leakage meets the fire source and explodes, with the progress of the explosion, the overpressure generated by the explosion increases rapidly at first, reaches the peak value, and then decreases; when the wind speed is 0 m/s and 2 m/s, the starting time of the change is basically the same, and the time when the wind speed is 4 m/s reaches the peak value is delayed; Fig. 6 (b) can be seen that the temperature after the gas cloud explosion decreases. The variation trend of the degree is first rising rapidly, then keeping at the peak value, then slowly decreasing, and finally reaching the normal temperature, in which the variation trend of the wind speed of 0 m/s and 2 m/s is basically the same; this is because when the wind speed is small (0 m/s and 2 m/s), the momentum of the gas cloud itself plays a dominant role in the diffusion process, and the distribution and coverage of the gas cloud are relatively different Near. With the increase of wind speed, when the speed is larger (4 m/s), wind speed and wind direction become the dominant factors in the process of gas cloud diffusion, which can dilute the gas cloud diffusion and inhibit the explosion.

3.3. Influence of wind direction on gas cloud explosion
When the leakage speed is 4 kg/s and the wind speed is 4 m/s, the distribution of the gas cloud explosion pressure field under the influence of different wind directions is shown in Fig. 7.
It can be seen from Fig.7 that when the combustible gas cloud in the tank farm explodes, the influence range of overpressure is different under different wind directions. When the wind direction is northeast, the impact area of overpressure is the largest, and is the smallest when the wind direction is east. Most of the overpressure is below 0.04 bar, this is because the leakage rate is small, the quality of the leaked LPG in the tank area is less, and the wind speed is higher, which has a dilution effect on the diffusion of the gas cloud. The gas cloud in the tank area covers a larger area, but the concentration is lower. Therefore, after the explosion, the pressure is lower.

When the leakage speed is 4 kg/s and the wind speed is 4 m/s, the overpressure and temperature changes on the surface of No.1 storage tank when the gas cloud explodes under different wind directions are shown in Fig.8.

It can be seen from Fig.8 that the trend of overpressure and temperature is similar to that in Fig.6. When the wind direction is east, the overpressure and temperature first reach the peak, which are 0.0527 bar and 2267 K respectively. When the wind direction is north and northeast, the overpressure and temperature are similar, which are 0.0625 bar and 2265 K, 0.0631 bar and 2245 K, respectively.

4. Conclusions

In this paper, the explosion simulation of LPG gas cloud is carried out, the explosion consequences of the LPG storage tank leakage are studied, and the dynamic changes of PROD, explosion pressure field and temperature field under different working conditions are obtained. The main conclusions are as follows.
Through the simulation of the leaking gas cloud explosion, the propagation process of the flame, the change process of the overpressure, the temperature and the main impact area are obtained.

(2) The greater the leakage rate, the greater the impact area of the gas cloud explosion, and the higher the explosion overpressure and temperature.

(3) When the speed is high (greater than 4 m/s), the wind speed dominates the diffusion of the gas cloud. The higher the wind speed, the faster the heavy gas will be diluted by the ambient gas, and the explosion will be suppressed.

(4) Under the influence of different wind directions, the explosion impact area is different. In this simulation, when the wind direction is northeast, the overpressure impact area is the largest, and the influence is the least when east wind.

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