Study on Influence Characteristics of Natural Gas Leakage in Long-distance Pipelines

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Abstract. In order to study the diffusion characteristics of leaking natural gas in long-distance pipeline, natural gas leakage model were established and natural gas diffusion was numerically simulated by fluent. The influences of different airflow velocities and leakage apertures on the concentration distribution of natural gas were analyzed. The research shows that airflow velocity promotes the diffusion of natural gas, and the greater the airflow velocity, the wider the diffusion range and distance of natural gas towards the downwind. The larger the leakage apertures, the larger the concentration and diffusion area of natural gas. Airflow velocities and leakage apertures are the key factors affecting the accumulation of natural gas near the surface. In the case of natural gas leakage in long-distance pipelines, people near the leakage hole should be evacuated to the upwind direction to minimize the risk.

1.Introduction
With the great increase in the use of clean energy and natural gas in China, 99% of natural gas in China is transported by pipeline[1]. However, due to various external factors, natural gas pipeline leaks[2], which will seriously lead to explosion accidents. With the increase of pipeline construction projects, the distance between natural gas pipelines and human buildings is reduced, and pipeline leakage accidents caused by human causes are gradually increasing. For example, the Guizhou section of Cnpc natural gas pipeline exploded, resulting in 8 deaths and 35 injuries in 2017[3]. According to the current situation of natural gas pipeline construction and management in China, it is of great significance to study the leakage and diffusion characteristics of natural gas with different influencing factors. At present, the research of relevant scholars mainly focuses on the influence of different factors on the diffusion pattern of natural gas[4-7]. In this paper, CFD numerical simulation software is selected to study the influence of airflow velocity and leakage aperture on the diffusion of leaking natural gas in the atmospheric environment, which would provide theoretical basis for formulating scientific and effective risk control measures.

2.Numerical simulation method

2.1.Physical and mathematical model of natural gas leakage
In this paper, the diffusion of leaking natural gas is studied. In order to simplify the calculation process and improve the accuracy, two-dimensional model is established to study the diffusion of leaking natural gas in a certain diffusion area. Diffusion area size is set to be 100m×100m, the diameter of the natural gas pipeline is set to 1016mm, and the leakage hole is located directly above the pipeline. The physical model of natural gas leakage and diffusion in long-distance pipelines are shown in Figure 1.
As the concentration of natural gas in the atmospheric environment have been diluted for a certain time and distance, the heat exchange among gas and air are ignored in the calculation process, and the physical model can be simply described as the flow of natural gas in the atmospheric environment. In the numerical calculation, the gravity is considered and standard $\kappa$-$\varepsilon$ equation is adopted to calculate the turbulent flow of the fluid.

2.2. Boundary conditions and assumptions
The entrance of the airflow adopts the boundary condition of velocity inlet, The natural gas leakage hole adopts the boundary condition of velocity inlet and the exit of the airflow adopts the boundary condition of pressure outlet. The assumptions are as following: the air is incompressible; there are no people and buildings in the atmospheric environment; natural gas is only one component of methane.

2.3. Parameters
According to the previous research, the diffusion of natural gas are influenced by different factors, so in this simulation leakage velocity, leakage aperture and airflow velocity are considered as mail factors influencing natural gas diffusion.

(1) Leakage velocity
According to the “West-East gas transmission project”, the working pressure of natural gas pipeline is no more than 8Mpa, and according to the pressure design and pressure classification of GB 50251-2015 “Code for design of gas transmission pipeline engineering”, the common pressures of the long-distance pipeline are selected to be 2Mpa, 3.5Mpa and 5Mpa, and the leakage velocities of natural gas are 98.9m/s, 123.9m/s and 146.52m/s respectively in this simulation.

(2) Leakage aperture
According to accident statistics, small hole leakage are the common natural gas accidents, so the leakage aperture are selected as 40mm, 120mm, 320mm.

(3) Airflow velocity
This paper selects two representative velocities in the simulation: 5 m/s, 10 m/s.

So the concentration distribution of natural gas in the atmospheric environment are simulated and calculated.
3. The leakage and dispersion of natural gas

3.1. The influence of airflow velocity and leakage velocity on natural gas diffusion

When the airflow velocity and leakage velocity changed, the natural gas diffusion would be affected accordingly. So in this simulation the airflow velocity and leakage velocity are changed and the leakage aperture is 40mm. The parameters are set as follows: the atmospheric airflow velocities are v=5m/s, 10m/s, and the gas leakage velocities are u=98.9m/s, 123.9m/s, 146.52m/s. The concentration distribution of natural gas are shown in Figure 2.

![Figure 2. The concentration distribution of natural gas (d=40mm)](image)

It can be seen from Figure 2 that the maximum concentration of natural gas is 35%. At the same leakage velocity, when the airflow velocity increases, natural gas diffuses to the downwind area, the diffusion offset angle of natural gas increases, and the diffusion height decreases. Airflow velocity and vortex lead to an increase in the area of dangerous area, and the dangerous area changes from middle to high altitude to near the ground, thus increasing the risk of natural gas explosion. Under the same airflow velocity and three different leakage velocities, the natural gas diffusion direction is roughly the same. With the increase of leakage velocity, the natural gas deflection angle increases, natural gas gathers near the ground, and the area of dangerous area increases, thus increasing the explosion risk. Therefore, airflow velocity and leakage velocity are the key factors affecting the risk of natural gas accumulation near the ground.

3.2. The influence of leakage aperture on natural gas diffusion

From the above analysis, we can see that the airflow velocity has a certain effect on the leakage and diffusion characteristics of natural gas, and different leakage apertures also are the important factors on the leakage and diffusion path and range of natural gas in vertical plane. In this paper, the leakage aperture are d=40mm, 120mm, 320mm, the airflow velocity v=5m/s and the leakage velocity u=98.9m/s are selected to simulate the concentration distribution of leaking natural gas. The working conditions are shown in table 1. The single factor influences of leakage aperture on natural gas diffusion are analyzed.

| Number | Leakage aperture (mm) | Airflow velocity (m/s) | Leakage velocity (m/s) | Leakage flow (kg/s) |
|--------|-----------------------|------------------------|------------------------|---------------------|
| 1      | 40                    | 5                      | 98.9                   | 13.81               |
| 2      | 120                   | 5                      | 98.9                   | 105.22              |
| 3      | 320                   | 5                      | 98.9                   | 201.71              |
Since the velocity vector distribution has a direct impact on the concentration distribution of natural gas, firstly, the velocity vector distribution of natural gas with different leakage apertures are analyzed, and the velocity vector diagram of natural gas is shown in Figure 3.

![Velocity vector diagram of natural gas with different leakage apertures](image)

**Figure 3.** Velocity vector diagram of natural gas with different leakage apertures ($v=5\text{m/s}, u=98.9\text{m/s}$)

It can be seen from Figure 3 that with the increase of leakage height, the natural gas jet velocity decreases and gradually begins to diffuse around; With the increase of leakage aperture, natural gas leakage velocity and leakage height increase, and the downward direction offset decreases, and vortex begins to appear. Then the concentration distribution of natural gas with different leakage apertures are analysed, as shown in Figure 4.

![Concentration distribution of Natural gas with different leakage apertures](image)

**Figure 4.** Concentration distribution of Natural gas with different leakage apertures ($v=5\text{m/s}, u=98.9\text{m/s}$)
It can be seen from fig.4 that when the leakage aperture is d=320mm, the horizontal deviation of natural gas is small, but the diffusion height in the vertical direction increases. Although convection generated between natural gas and air, the influence is small, the longitudinal and transverse height of natural gas leakage diffusion increases, and the dangerous areas of leakage are concentrated near the ground and at high altitude. The leakage amount of natural gas with a leakage aperture of 40mm is much lower than that of the other two leakage apertures, and the diffusion of natural gas is greatly influenced by airflow velocity in the horizontal direction. Compared with the leakage aperture d=120mm, the deviation degree in the horizontal direction is greater, the deviation angle becomes larger, and the leakage height of natural gas decreases. Through the analysis of natural gas concentration with different leakage apertures, it can be seen that with the increase of leakage aperture, the concentration and diffusion range of natural gas increase, the offset height in downwind direction increases, and the included angle with horizontal plane increases. The larger the leakage aperture, the greater the leakage velocity of natural gas, and the smaller the influence of airflow velocity on natural gas diffusion. The leakage velocity of natural gas in the vertical direction is far greater than the diffusion velocity in the horizontal direction. Dangerous areas also spread from low altitude to high altitude areas. However, considering the accident risk, the risk degree in the space near the ground is greater than that at high altitude. Leakage aperture is the key factor affecting the risk of natural gas accumulation near the ground.

4. Conclusion
This paper aims to analyse the influence of airflow velocity and leakage apertures on the concentration distribution of natural gas in the atmospheric environment, and the diffusion characteristics of natural gas were acquired. The results show that:

(1) With the action of buoyancy and gravity, the diffusion process of natural gas is mainly upward diffusion, and as time goes on, its concentration gradually decreases, and the range of upward diffusion gradually expands.

(2) Airflow velocity has a significant impact on the diffusion process of natural gas. When the airflow velocity is small, the diffusion range of natural gas in the downwind direction is small, and it is mainly the upward diffusion with the action of buoyancy; when the airflow velocity is high, the downward deviation of natural gas becomes larger, and the diffusion range increases. With the increase of leakage velocity, the leakage amount of natural gas increases, the concentration of natural gas in the leakage area near the ground increases, and the explosion risk increases.

(3) Leakage apertures also have a great influence on the diffusion of natural gas. With the increase of leakage aperture, the amount of natural gas leakage increases, the range of natural gas diffusion toward upward and downward wind direction increases, and the leakage danger area also diffuses from low altitude to high altitude.

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