The Study of Gas Leakage Dispersion Rules in the Integrated Utility Tunnel

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Abstract: This paper focuses on underground gas pipeline leakage accidents. Through the use of CFD numerical simulation method for accident ventilation control, this paper has kept the natural gas concentration within a safe range. At the same time, through ventilation, we studied the control effect of natural gas concentration in the utility tunnel under different air inlet spacing and different ventilation control. Therefore, by using a reasonable accident ventilation measure based on the CFD numerical simulation method, we hope to improve the safety performance level of natural gas pipeline operation.

Key words: Underground Integrated Utility Tunnel; Gas Leakage; Numerical Simulation

1. Introduction

In recent years, China has continued to increase its investment in the construction of urban underground integrated utility tunnels, aiming to enhance disaster prevention and mitigation capabilities and pipeline safety levels, optimize policies, expand the scope of tunnel construction promotion, and better meet the diverse needs of the people. In fact, these measures not only fully reflect the nation's high attention to the construction of urban integrated utility tunnels but also show the government's significant focus on urban infrastructure construction. Therefore, it can be predicted that the construction of urban underground integrated utility tunnels will maintain rapid development in the future, injecting new energy into urban progress and offering stronger support for the nation's modernization construction.

Since 2014, the nation has made a significant investment in underground integrated utility tunnels, making it easier for daily maintenance and servicing of various pipelines, including gas lines. To beautify the cityscape, previously overhead-laid power and communication lines can be incorporated into integrated utility tunnels, completing the transformation of power supply and communication pipelines. Natural gas pipelines, as a high-risk type of line, are set separately in a sealed gas chamber, and any leakage or explosion can have serious consequences. Therefore, this article urgently needs to conduct an in-depth study of the leakage of natural gas pipelines in gas tanks and improve their safety operating procedures to reduce potential safety hazards.

2. Literature Review

Liu Xiuxiu (2018) pointed out in the theoretical and experimental research of the gas leakage and diffusion in an integrated utility tunnel that adopting integrated utility tunnels for urban underground space planning and development is of great significance for urban pipeline maintenance and management. This is an important measure that the country strongly supports in modern urban construction projects. The use of integrated utility tunnels can concentrate various pipelines in one tunnel, greatly improving the utilization of urban underground space, reducing the cost of underground space development, and decreasing pipeline maintenance costs. In addition, integrated utility tunnels can effectively protect the urban ecological environment, prevent the decline of groundwater levels, and avoid issues such as soil settlement. Therefore, the implementation of integrated utility tunnels has a positive promotion effect on urban green development and ecological construction.

The study introduces the concept of soil density and classifies it into natural soil, dense soil, and blocky soil. Wang Daqing and others established a simplified calculation method that combines pipeline and large-pore models based on the existing leakage patterns and analyzed it. Kostowski WJ and others analyzed the relationship between the flow rate and pressure during the actual leakage process of the pipeline. The results showed that there was no significant correlation between the flow coefficient and pressure variation in the medium pressure region.

3. Gas Leakage Diffusion Theory Foundation

According to the molecular movement theory, all types of substances engage in irregular movement. Gas molecules are no exception and constantly undergo free movement. When there is a concentration difference between a high-concentration gas region and a low-concentration gas region, gas molecules will move towards the low-concentration region until the two regions reach a concentration equilibrium. This is called gas diffusion. The rate of gas diffusion is directly proportional to its concentration gradient - the greater the concentration difference, the faster the diffusion rate. Compared with other types of molecules, gas molecules have larger distances between them and more violent motion, making their diffusion phenomenon more obvious.

The conservation law of fluid motion serves as the foundation of fluid mechanics, and gas diffusion is no exception. Different fundamental equations can be set in numerical model software to simulate and predict gas diffusion behavior in various situations. These equations include continuity equation, momentum equation, energy equation, and component equation, etc. The continuity equation requires conservation of mass and volume at all times; the momentum equation describes the inertia and viscosity characteristics of gas; the energy equation involves heat transfer modes like conduction, radiation, and convection; and the component equation regulates the concentration and intercomponent interaction of different components in the gas. Simulation and solving of these equations enables more accurate prediction of gas diffusion range and potential impact.

4. Integrated Pipe Gallery Model

Taking the natural gas pipeline in the integrated pipe gallery as the research object, we analyze the transient leakage process of methane gas after a gas pipeline leakage. The cross-sectional dimensions of the underground integrated pipe gallery are 1.8m x 3.5m, with a gas pipeline diameter of 0.6m. The length of the pipe gallery is Z=100m. The inlet size is 1m x 1m, located 5 meters from the left isolation wall, and the outlet size is 1m x 1m, located 5 meters from the right isolation wall. The leak hole diameter is 40mm.

After certain simplifications, the simulation model is shown in Figure 4-1. The inlet of the fan is simplified as a velocity inlet, and the outlet of the induced draft fan is simplified as a pressure outlet. The Fluent software is applied to analyze the transient process of natural gas leakage.

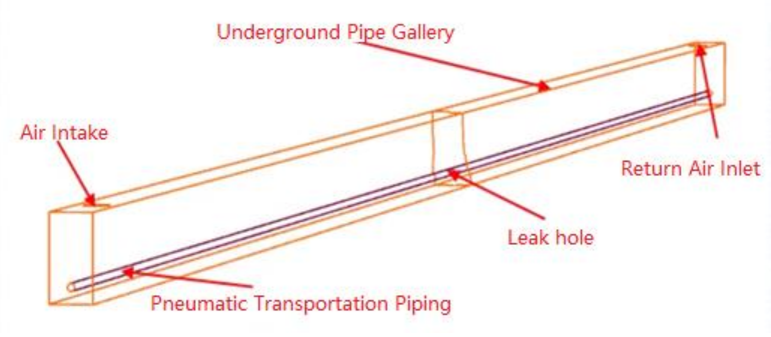


Figure 4-1 Simplified model of pipe gallery

The accuracy of the simulation results primarily depends on the grid partitioning accuracy of the model. Therefore, to complete numerical calculations within a controllable time, it is necessary to set a reasonable grid size. Research has shown that reducing unnecessary grid quantities, i.e., optimizing the grid partitioning, helps to reduce computational complexity and shorten the required time. Setting a reasonable grid size ensures both the accuracy of the simulation results and avoids excessive waste of computational resources.

This article uses the embedded meshing feature, “meshing”, of ANSYS to partition the model's grid. In addition, for the entire model, volume meshing is also used for definition and partitioning. This grid partitioning method not only ensures the accuracy of the model but also improves computational efficiency, providing substantial assistance to model simulation and engineering applications. Based on the coarseness or density of the model's grid partitioning, this article classifies it into different levels, generating the grid shown in Figure 4-2.

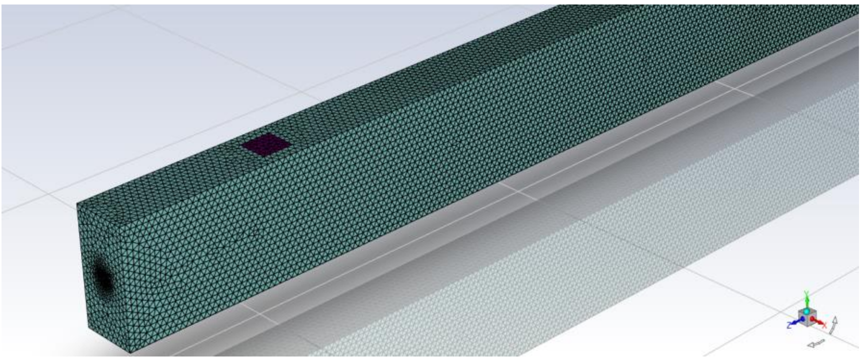


Figure 4-2 Grid local display

5. Gas Leakage Diffusion Analysis

After a small hole leak occurs in an underground gas pipeline, natural gas will continuously spread toward the exhaust port due to the influence of ventilation. This is because natural gas is light in weight, highly combustible, and easily spreads into the air along the direction of gas flow, posing a risk of fire or explosion.

Effective control measures must be taken under leakage conditions to prevent accidents such as explosions caused by high-concentration natural gas. In order to better understand the impact of natural gas leakage on the surrounding environment, we use a 3D leakage model of an underground gas pipe gallery for simulation analysis. As shown in Figure 5-2, the model considers important parameters such as the structural characteristics of the pipe gallery, the location of natural gas leakage, and the leakage rate, and adopts different incident ventilation methods, such as mechanical ventilation and smoke exhaust ventilation, to control the concentration of natural gas in the surrounding area.

From Figure 5-1, it can be seen clearly that natural gas gradually spreads to the surroundings and the concentration gradually decreases. In the time period from 150s to 190s, we observed that the concentration of natural gas gradually decreased from the initial 7% to approximately 5%. At 190s, the concentration of natural gas continued to decrease and dropped below 5%. The contour map of the natural gas concentration change is shown in Figure 4-6, and the change in natural gas concentration is shown in Figure 5-3.

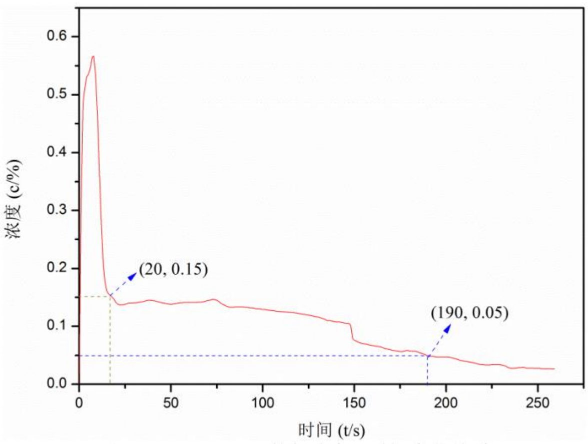


Figure 5-1 Relationship between natural gas concentration and time at leakage hole

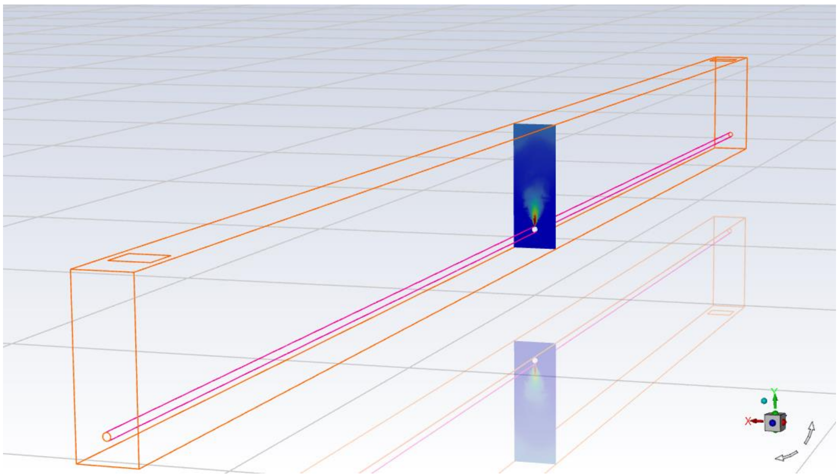
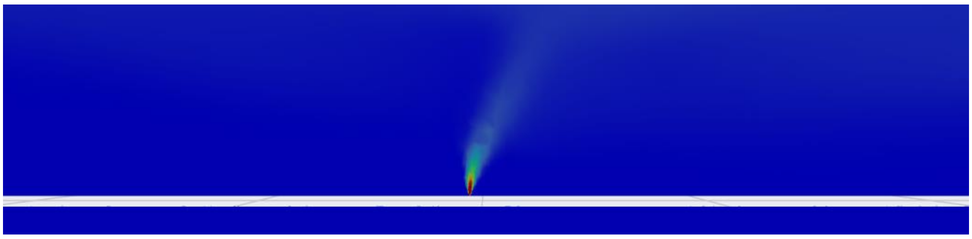
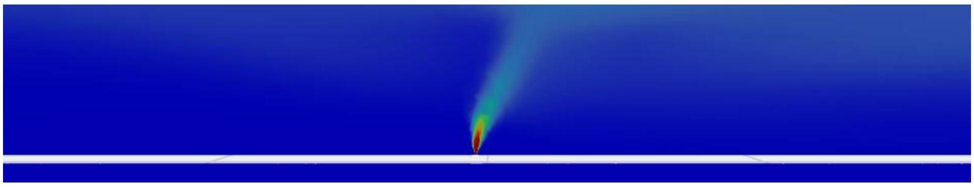


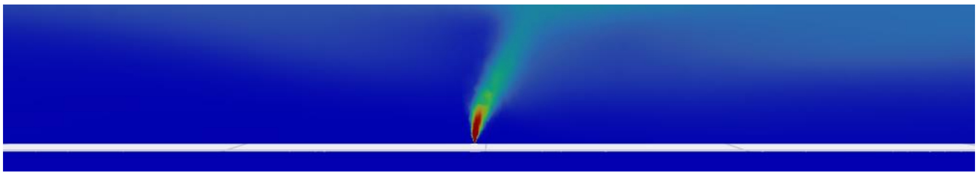
Figure 5-2 Three-dimensional model of gas leakage in underground pipe gallery



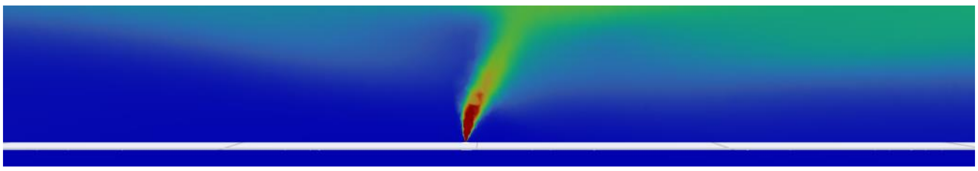
(a) 1s



(b) 3s



(c) 5s



(d) 8s

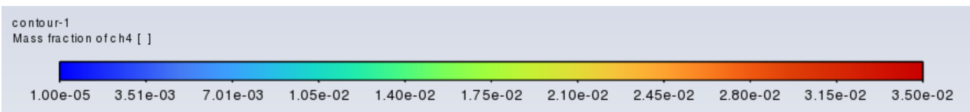


Figure 5-3 1 ~ 8s slice Z = 50m natural gas concentration cloud map

According to Figure 5-3, once a leak occurs, natural gas rapidly spreads outward. The concentration of natural gas in the dispersion area can reach up to 80%.

During the time period of 1 to 8 seconds, when the natural gas jets from the leak hole to the top of the conduit and flows to both sides, its movement speed is relatively high and the high concentration area is concentrated and distinct. The influence of the external environment is minimal, resulting in less dispersion. Therefore, the concentration of natural gas continues to increase at a distance of 50 meters from the cross-section. By the time of 8 seconds, the average concentration of natural gas at that cross-section reaches its peak, exceeding 56%.

At this point, during the downstream process of the gas along the wall, the kinetic energy of the high concentration natural gas gradually dissipates, and the dispersion area continues to expand. The influence of the external environment on the dispersion of natural gas intensifies, further increasing the quantity of natural gas spreading from the leak hole to other areas. Due to the accident ventilation and the decrease in the leakage rate of natural gas per unit time, after approximately 100 seconds, the concentration of natural gas in the lower part of the conduit gradually decreases from about 8% to below 5%, and this phenomenon gradually spreads to the surrounding areas.

This leads to the phenomenon of increased natural gas concentration in the left-side area of the gas pipeline, which is more concentrated compared to the concentration of natural gas in the right-side area.

6. Conclusion

The purpose of this article is to control small hole leakage accidents in urban underground gas conduit by adopting the method of accident ventilation. To achieve this, a gas pipeline segment with a length of 100 meters was selected as the research object. Subsequently, leak conditions were chosen with a pressure of 0.2 MPa, pipe diameter of 600 mm, and leak hole diameter of 40 mm. Finally, the effectiveness of controlling the concentration of natural gas in the conduit by implementing accident ventilation was determined.

Due to the initial high leakage rate of natural gas at the leak hole, it poses a serious threat to safety. At the same time, the presence of the upper wall surface of the conduit results in the phenomenon of “ceiling jet”, where high-speed natural gas encounters this wall surface and a large amount of gas is directly discharged upwards, increasing the hazard caused by the leak.

In addition, the upper part of the conduit remains in a high-concentration natural gas area for a long time, which is a concentrated area of concern and should not be ignored. It is necessary to take timely measures to ensure personnel safety and proper operation of facilities. Therefore, in order to prevent similar accidents, corresponding preventive and control measures must be taken, and safety issues during operation must be strictly managed in accordance with relevant standards to ensure the safety and reliability of the entire gas pipeline system.

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