Evaluation of Fire Mitigation and Control Approaches in Gas Processing Plants

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Abstract :- With the rapid development of urban construction and increasing industrial demands, numerous long-distance oil and gas pipelines have been constructed and are now operational in China. During transportation, these pipelines are susceptible to leakage incidents caused by various internal or external factors. If the concentration of leaked oil or gas mixed with air reaches its flammability or explosiveness limits, the presence of an ignition source in the vicinity could lead to fire or explosion accidents, resulting in casualties and severe property damage. Consequently, research on risk analysis and evaluation of oil and gas pipelines has become a key focus within the field of safety engineering in recent years. Therefore, it is essential to conduct fire risk assessments to ensure the safe operation of long-distance oil and gas pipelines.

In this study, the risk characteristics of long-distance oil and gas pipelines were first analysed, followed by a fire risk assessment based on Quantitative Risk Analysis (QRA). Taking a natural gas pipeline as an example, the affected area (death radius) and individual fire risk contour lines were mapped using the CASSTQRA software. For the natural gas pipeline studied, the death radius was determined to be 148.42 m, and the areas enclosed by the individual risk contour lines of 3×10^-7 and 1×10^-6 did not include high-density residential zones, public gathering areas, highly sensitive sites, critical facilities, or other densely populated locations. Thus, the fire risk of the natural gas pipeline was considered acceptable. Finally, this paper proposes corresponding preventive and control measures to ensure the safety of pipeline transportation. The findings of this study provide practical significance for risk assessment and safety management of long-distance oil and gas pipelines.

Keywords : Gas Plant, Quantitative Risk Analysis, Fire and Explosion Control

Introduction

Leakages in oil and gas pipelines can occur during transportation due to ruptures caused by various internal or external factors such as corrosion, material ageing, and substandard construction quality. When the concentration of the leaked natural gas mixed with air reaches its flammability or explosiveness limit, there is a high possibility of fire or explosion accidents. According to statistics, numerous oil and gas pipeline accidents have occurred in China since 2000 [1, 2]. Such fire or explosion incidents pose serious threats to human lives, surrounding equipment, and infrastructure.

For example, on January 1, 2002, in Daqing city, an underground natural gas pipeline ruptured, leading to a gas explosion that resulted in at least six fatalities, two individuals severely injured, and two with minor injuries. Another incident occurred on April 20, 2004, in Huainan city during pipeline maintenance, where an explosion killed two people, severely injured one, and slightly injured six others. Furthermore, on November 22, 2013, a major oil pipeline explosion in Qingdao city claimed 62 lives and injured 136 people. These incidents underscore the practical importance of conducting risk research on natural gas pipelines to safeguard lives and property.

Therefore, it is crucial to study the risks associated with long-distance oil and gas pipelines to prevent loss of life and property. In recent years, research on risk analysis and evaluation of oil and gas pipelines has become a significant focus in the field of safety engineering. Various calculation models, such as the Quantitative Risk Analysis (QRA) model, Uniform Dispersion Model (UDM), Baker-Strehlow-Tang (BM) model, and FEM3 model, have been developed to simulate oil and gas leakage diffusion and evaluate pipeline risks. These models have been applied to different scenarios, including chemical equipment and process pipelines [6-8]. Additionally, software such as PHAST has been utilised to analyse natural gas diffusion during leakage events.

However, assessing the individual fire risk remains critical for effective oil and gas pipeline risk management. In this study, based on pipeline risk analysis, a fire mathematical model and jet fire model for oil and gas were first developed. Subsequently, the consequences of fire accidents were evaluated using QRA, and the affected areas and individual risk were charted using the CASSTQRA software. Finally, the paper proposes several safety measures and recommendations. The findings of this study contribute significantly to the risk evaluation and safety management of oil and gas pipelines.

Comprehensive Risk Analysis of Long-Distance Oil and Gas Plant

The impact area of long-distance pipeline accidents is a critical factor in determining the overall risk associated with oil and gas pipelines. Typically, this affected area is categorised into two zones: the fatality (death) radius and the injury radius. The influence radius represents the threshold distance within which a pipeline leakage accident may result in fatalities, environmental pollution, property damage, or other undesirable consequences. Therefore, the influence area of a long-distance pipeline is defined as the threshold distance extending outward from the pipeline to its surroundings.

Since accidents along long-distance oil pipelines can occur at any point along their route, the entire pipeline is considered a continuous series of potential hazardous sources. When evaluating the worst-case scenario where an accident could occur at any hazard point, the influence area on both sides of the pipeline can be conceptualised as circular zones with the accident point as the centre. The influence radius (R) defines these circles, which, when extended along the pipeline route, can be approximated as a rectangular area encompassing the pipeline or a series of overlapping circular regions.

Individual risk serves as a key quantitative index to assess potential loss of life and is fundamental in quantitative risk assessments. Individual risk refers to the probability of death for a person located at a fixed position within the region, arising from various potential accidents such as fires, explosions, or toxic gas leaks. This risk is typically represented through risk contour lines illustrating zones of equal individual mortality probability.

Fire Consequence Analysis Model

Fire analysis of a gas plant in the industry Temperature and Stress analysis. Concrete has low thermal conductivity, so in reinforced concrete structures, the concrete cover acts as insulation to the reinforcing bars during a fire. Generally, concrete buildings perform well in real fire incidents, and collapse is rare. Researchers have been interested in modeling the behavior of reinforced concrete under fire for over 30 years. The modeling process involves two steps: (i) defining the realistic fire exposure boundary conditions and the heat transfer properties of concrete to estimate heat propagation at different positions of the element and time intervals, and (ii) analyzing the element's structural and mechanical properties while considering the simultaneous effects of heat and mechanical loads. The concrete beam is modeled using a three-dimensional solid part.

The initial simulation involves using a heat transfer step to model the fire condition and temperature analysis. The thermal properties are utilized in the thermal analysis, and the fire condition is assigned to the bottom surfaces of the beam using a temperature diagram for a duration of two hours. Following the completion of the thermal simulation, all results including nodal temperature and heat flux can be obtained.

In the second simulation, the Concrete Damaged Plasticity (CDP) data is taken into account, which depends on temperature. The elasticity and expansion properties, which are also temperature-dependent, are incorporated to account for the effects of heat on them. By using the temperature-dependent elasticity, expansion, and CDP model, the temperature from the thermal simulation in the fire situation can be translated into stress and strain. The structural analysis is modeled using a general static step with some changes in the convergence model. Fixed boundary conditions are applied to both ends of the beam. The results obtained from the thermal analysis are then transferred to the structure model for analysis.

Following the simulation, various results such as stress, strain, plastic strain, displacement, and more are obtained. These results are a consequence of the temperature increase during the fire analysis.

Under fire conditions, appropriate materials must be used. For this purpose, specific heat and conductivity values that are dependent on temperature are utilized. Similarly, specific heat and conductivity are also used for the steel bars. A heat transfer step lasting two hours is selected, and three types of heat transfer methods are applied. The convection method, using the fire condition as a film condition and applying the fire temperature amplitude, is chosen. Radiation is applied to the surfaces of the concrete beam, and conduction between the steel bars and the concrete beam is also considered. Fixed boundary conditions are assigned to both ends of the beam, and the entire model is given an initial temperature. To obtain accurate results, the mesh should be fine.

Conclusion and Suggestions

- Fire incidents can occur when leaked oil or gas mixes with air and is ignited by an ignition source during transportation in long-distance oil and gas pipelines. Among the various types of fire accidents, jet fires pose the greatest challenge, particularly in scenarios involving pressurised or pressure-liquefied flammable materials. Research on fire risks in long-distance oil and gas pipelines holds significant theoretical and practical importance for ensuring the safety of both personnel and property.

- The impact area of long-distance pipeline accidents is a key factor in determining the overall risk associated with oil and gas pipelines. This influence radius is generally categorised into fatality (death) radius and injury radius. Thus, the influence area of a long-distance pipeline is defined as the threshold distance extending outward from the pipeline to its surroundings.

- According to Gas regulations, long-distance oil and gas pipelines are classified as major hazard sources, and the acceptable individual risk criteria are strictly defined. In high-density residential areas and public gathering places, the individual risk must not exceed 1×10^-6 per year. In highly sensitive areas, critical facilities, and other specially designated high-density zones, the acceptable individual risk is limited to 3×10^-7 per year.

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