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A Leak Detection Method for Underground Polyethylene Gas Pipelines Using Simulation Software Ansys Fluent

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P A P E R I N F O

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A B S T R A C T

In this subsection, a simulation model of underground pipeline leaks was created. Modeling the flow fields of overhead pipelines and underground pipelines with different soil porosity was conducted. The influence of the underground environment and soil porosity on the pipeline leakage field was analyzed. The influence of changes in the underground environment and soil porosity on the loss of kinetic energy at gas leakage was defined. Thus, the law of change in the characteristics of the sound signal of a leak on the pipe wall was obtained. Based on the results of study, it was determined the area of damage to a gas pipeline which is depended on proportionality of the diameter of the gas jet. As the gas is released from a crack in the gas pipeline and with different porosity of the pipe material, the gas diffusion occurred. As a result, the explosion zone increased which ultimately the release of gases into the environment under the influence of pressure increased.

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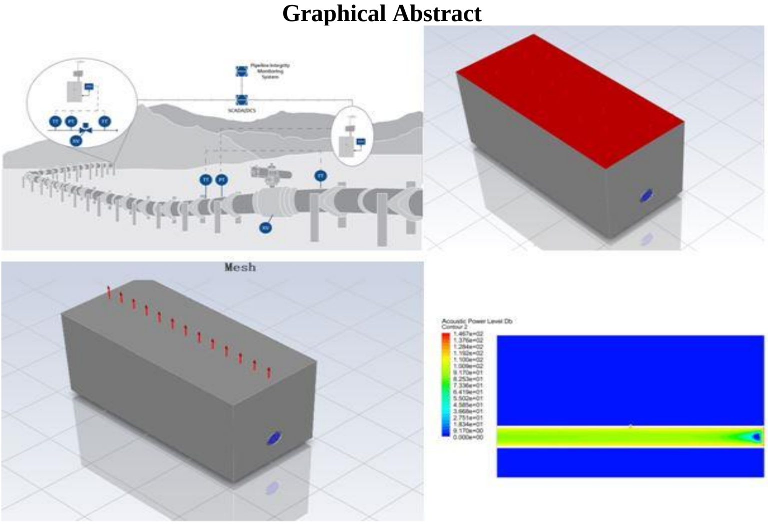
Graphical Abstract



1. INTRODUCTION

Natural gas leaks from pipelines lead to environmental and economic consequences (1). There are a number of risks of leaks due to pipeline corrosion (2-4). Emissions of methane into the atmosphere are considered as emissions and leaks, which is detrimental to the environment and public health (1, 5, 6). There are frequent accidents due to gas leaks on gas pipelines, as well as fires (7-9). The main factors that cause leaks in

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gas pipelines are external loads due to corrosion and deformation of pipelines (see Figure 1).

Methane leaks from gas pipelines can have serious consequences for the environment (10-12). For this reason, gas pipelines become expensive to maintain and unsafe due to neglect of gas leaks (13, 14). The escaping gases enter the surrounding air and form explosive mixtures. If the mixture is not too concentrated or too thin, an explosion will not occur. Gas concentration depends on the distance from the pipe. For research, it is important to understand the amount of gas allowed in the air when the concentration of its components changes. Siddiqui et al. (15) and Lu et al. (16) investigated gas flow in gapped pipes assuming adiabatic and isothermal flow. In this study, using spectral methods it is possible to determine a small difference. Spectral methods are an alternative to characteristic and finite difference methods (17). This method used Jacobian polynomials to estimate spatial derivatives. The impact of cracking in gas pipelines was studied isothermal model by Moloudi and Esfahani (7), can be used a characteristic method considering the flow, which is not determined in pipeline. The resulting rate of gas leakage from the gas pipeline was 18% lower than expected by Liu et al. (18). Deblieck et al. (19) provided a detailed description of the acoustic flow of gases flowing through the pipe showed a constant mass flow rate due to an increase in pressure loss along the flow rate.

Fedorov et al. (20) described a model for chlorine gas emissions. This CFD model showed transitional gas flows from laminar to turbulent in a one-dimensional simulation view (11, 12). Some parameters were studied during gas flow through the pipeline both in steady and unstable conditions. In some studies, researchers divided problems into two general categories for estimating pipeline leak rates: in conditions where, when a pipe is damaged, the diameter is less than the main diameter. Yayla and Leevers (21) proposed a description of a mathematical model of gas leakage. The model they proposed was a combination of the two hole and tube models. Sajid et al. (22) also reviewed the same topic. What distinguishes the previous study from the work of Yayla and Leevers (21) is that Bo et al. (23) presented the idea of the presence of an ideal gas in the pipe is completely denied, and also that the compressibility coefficient was used in the equation of state of the gas.

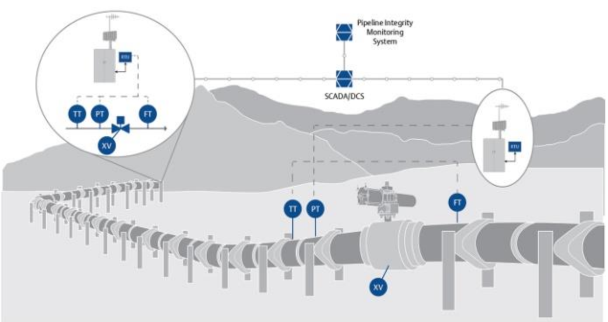

Figure 1. Gas pipeline leak detection methods

At the same time, the average leakage rate was 30% of the gas flow rate, which could be described by the proposed Fenning equation discussed by Bo et al. (23). The findings which provides an understanding of the calculation of the volume of natural gas that flows from the gas pipeline. At the same time, they neglected such a concept as kinetic energy, and argued that the proposed model can estimate the flow value than other mathematical models. Cui et al. (24) investigated the model proposed by Nikolaev et al. (25) which was improved by considering the change in gas energy up to 7% due to the proposed mathematical models for calculating the flow. Fetisov et al. (26) proposed the analytical methods of regression analysis for modeling hydrocarbon leaks from pipelines, taking into account local resistances and transient regimes.

In ground cover, Gafur et al. (27) studied turbulent gas flow using the finite element method. At the same time, in this work there was no model of the operation of a buried pipeline, which could well explain and show the study itself. There was also research and modeling analysis of the dependencies of such parameters as gas velocity, thermal conductivity, temperature, gas constant, etc. Fetisov et al. (28) investigated in transient and steady-state modes, mathematical models of gas flow, which described the compressibility of the gas and its effect on the pipe material through the gas equation of state. These equations were proposed for a polyethylene pipeline using isothermal and non-isothermal gas flow. Nikolaev et al. (29) described a mathematical model of gas flow from weld joints. Fetisov et al. (30) used a high-order finite-difference method to discretize the equations for simulating drilling in closed pipelines. Schipachev et al. (31) described a mathematical equation for calculating gas leakage due to an emergency failure of a gas pipeline. The results showed that leakage, which increases due to friction, depends on the nominal diameter of the pipe. Fetisov et al. (32) investigated pressure disturbances as the main basis for leak detection. They presented analytical model shows a pipeline that is connected to a tap and a gate valve.

The analyzing all the studies, we analyzed our own conclusions that the rate of gas leaks should be studied, but did not take into account the quantitative concentration of gas in the leak zone, which can be said about the relevance of this study. Therefore, this study attempted to numerically investigate the exhaust gas concentration at the rupture site and estimate the extent of the rupture zone using Ansys Fluent simulation software.

This paper is compiled in the following. In section 2 methods an attempt was made to calculate and detect gas leaks from an underground gas pipeline. In section 3 results numerical modeling of the results of the state of the polyethylene pipeline of the gas distribution network is presented. In section 4 presents a discussion of the results of the paper and recommendations for the control of gas emissions.

2. METHODS

2. 1. Simulation Model of an Underground Gas Pipeline Leak According to the principle of control, gas leak detection technology is divided into 3 categories: physical control technology, for example, cable and optical fiber sensor technology, acoustic or ultrasonic detection technology, visible light video camera, radioactive substances control technology, pipe wall parameter control technology, etc.; computer software detection technologies, common-statistics, neural networks, parametric analysis, mass balance, mathematical models, etc.; manual inspection and control technology (33, 34). The leak controller monitors leakage through the pipeline using a trolley or a Class 10-6 full-range probe detector, monitors operational pipelines and auxiliary structures, enclosed space in the specified range, and observes the environment to ensure that there is a leak in the pipeline (35, 36). Manual inspection and control technology is a widespread leak detection technology currently used in the urban gas industry (37-39).

Since the main component of both gas and biogas is methane, the suspected leak detected upon actual detection may be a disturbance caused by underground biogas (40). Other components that may be contained in the gas include ethane, propane, butane, carbon dioxide, nitrogen, etc. Other components that can be contained in biogas include nitrogen, ammonia, hydrogen sulfide, carbon dioxide, etc. Determination of the presence of ethane in the gas by gas chromatography allows you to quickly determine the presence of a gas leak.

When an underground gas pipeline leaks, the sound signal of a leak on the pipe wall is determined by the energy lost when the gas collides with the ground and the pipe wall, and the energy lost when the gas collides with the ground and the pipe wall mainly results from the loss of kinetic (41, 42) energy of the gas. In this subsection, a simulation model of underground pipeline leakage, modeling the flow fields of air pipelines and underground pipelines with different soil porosity was developed. The influence of the underground environment and soil porosity on the pipeline leakage field was obtained. The law of the influence of changes in the underground environment and soil porosity on the loss of kinetic energy during gas leakage was evaluated. Thus, the law of change in characteristics of the leakage sound signal on the pipe wall was developed. Figure 2 shows the leak model of an underground gas pipeline. The model includes a pipe with holes, a gas zone in the pipe and a soil zone in the upper part of the pipeline.

The total length of the pipeline is 1300mm, the outer diameter is 110mm, and the wall thickness is 10mm. The leak is in the middle of the pipeline, the diameter of the leak is 3mm. The Fluent software is used to create a leak model in a pipeline and simulate a convection field. As a result of modeling the comparison of the standard equations k-α and k-α-, it was found that the k-α equation better predicts the boundary layer of the wall at the leak hole; therefore, the k-α equation was chosen. To analyze the pressure distribution in the leak hole and the distribution of the leakage flow velocity in the pipeline in different operating modes, a stable flow field was obtained for leakage in different operating modes using analog calculations in a stable state. The medium in the pipeline is natural gas, the pipe wall is polyethylene; The pressure is set relative, the pipeline pressure is 0.4 MPa, in the soil zone there is a porous medium, the porosity coefficient is 0.7 mm. The boundary is set as follows: the boundary of the pipeline inlet is the pressure inlet, the boundary of the outlet and the upper boundary of the soil zone is the pressure outlet; The pipe walls are set as standard, the roughness constant is 0.01.

2. 2. The Process of Detecting an Underground Gas Pipeline Leak In order to avoid a secondary disaster as a result of a gas pipeline leak in the city and to restore normal gas supply as soon as possible, the main task is to quickly detect and eliminate the leak site of the gas pipeline. This article presents a method for detecting leakages of underground gas pipelines in cities. The working stages of applying the method are as follows: Select an appropriate well location method based on the analysis of reservoir characteristics (for example, preliminary determination of reservoir porosity and permeability by type of reservoir).

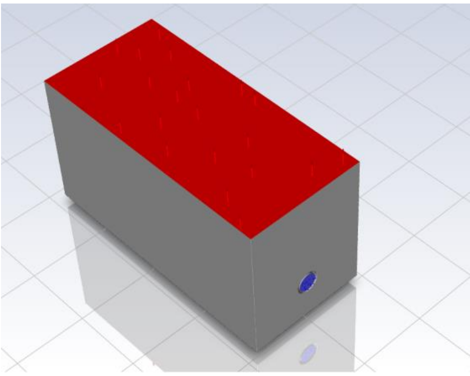

Figure 2. Model of gas leakage of underground pipelines under the ground

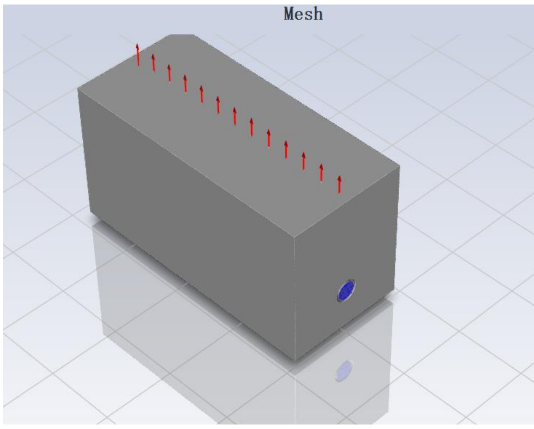

Figure 3. Model of gas leakage of underground pipelines from holes after drilling

Position the air injection and sounding holes, then drill a well into the ground using a drilling mechanism. Model of gas leakage of underground pipelines from holes after drilling is shown in Figure 3.

Connecting the rods with an explosion-proof fan and placing the rods in the air injection holes; The gas concentration analyzer is connected to the detector rod and placed in the detector hole. Figure 4 shows the gas concentration before vacuum suction operation.

Simultaneously start the air compressor and measure the gas concentration with the analyzer. Figure 5 depicts the gas concentartion after vacuum suction operation.

Using an ultrasonic sensor to detect the location of gas leaks from inside the pipeline, the frequency range is applied 0.2 MHz – 2 MHz.

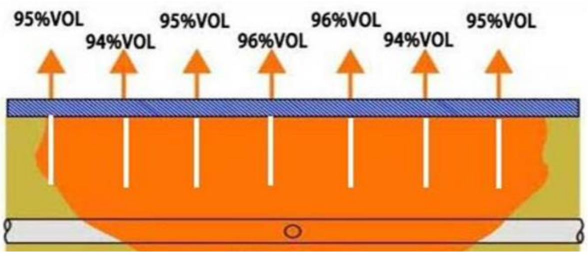

Figure 4. Gas concentration before vacuum suction operation

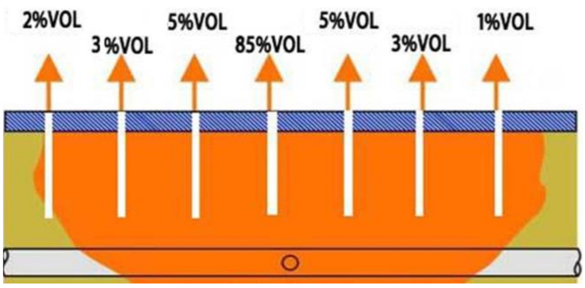

Figure 5. Gas concentration after vacuum suction operation

3. RESULTS

3. 1. Basic Condition of Polyethylene Pipeline in Gas Distribution Network

The sensing area has gas diffusion in the formation, the site of damage to the pipeline is located in the sensing area (category I). When the site of the pipeline damage is in the control area, the gas concentration-time curve will tend to increase and then decrease, eventually have a non-zero platform. This is due to the fact that when the gas injection rod begins to inject air, the residual gas in the formation (i.e. the gas spreading from the leak site into the surrounding formations) and the gas leak at the damage site are together directed into the detector hole, and the gas concentration increases with respect to time and reaches peak values. In duration of time, all remaining gas in the formation was gradually withdrawn, and only the leak from the pipe damage site continued to flow out. Thus, the gas-time concentration curve at a later stage will show a non-zero platform after peak, (Figure 6). At the same time, you can make sure that the control zone is selected correctly, and you should immediately dig a work pit to repair pipelines in the control zone.

The gas is dispersed in the formation of the probed zone, the place of damage to the pipeline is outside the zone (category II). When the site of the pipeline damage is outside the control area, the gas concentration-time curve will tend to increase and then decrease and eventually have a platform tending to zero. This is due to the fact that there are no places of damage to pipes with constant gas leakage in this area, and the gas residues in the formation quickly dissipate, resulting in zero gas being formed in the formation. This circumstance indicates the presence of gas diffusion in the layers of the control zone, that the place of damage to the pipeline is located outside it, which indicates an incorrect choice of the control zone. Therefore, a new detection zone should be selected, (Figure 7).

There is no gas diffusion in the formation in the detection zone, the place of damage to the pipeline is outside the zone (category III). In this case, the gas concentration is always zero, and the gas concentration - time curve is a straight line, where the concentration =

Figure 6. Simulation of gas leak detection using ultrasound

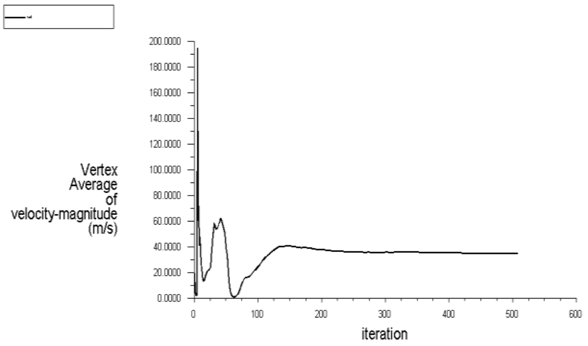

Figure 7. Result of modeling the detection of gas leaks using ultrasound

0. This circumstance indicates the absence of gas diffusion in the formation of the control zone, that the place of damage to the pipeline is outside the zone, which indicates an incorrect choice of the control zone. Therefore, a new detection zone should be selected.

The method of detecting gas leaks from inside the pipeline with an ultrasonic sensor allows you to determine more detailed leak sites that are the basis of excavation and repair work.

4. DISCUSSION AND CONCLUSION

This paper presents a way to quickly determine the location of an underground gas pipeline leak. This method avoids the development of a large area of the roadway, quickly localize the site of damage to the gas pipeline and carry out repairs, significantly reduce the area of development of the underground pipeline, reduce the impact of the incident on transport, reduce labor costs, the cost of excavation and repair of the roadway, save operating costs of the enterprise working with gas, avoid the negative impact of leakage gas for the safety of the city. In the case of leaks from underground gas pipelines in cities, it is necessary to quickly localize the leak site and eliminate it, especially if it is located near schools, hospitals, sports complexes, large shopping malls and other buildings with a massive crowd of people, since gas leaks into these buildings can have extremely serious consequences:

- The area of damage to a gas pipeline depends proportionally on the diameter of the gas jet that is released from a crack in the gas pipeline.
- With different porosity of the pipe material, gas diffusion occurs and, as a result, the explosion zone increases. Which ultimately increases the release of gases into the environment under the influence of pressure.

At the same time, the methods given in this article can be used for other gas pipelines, except for places of leakage of underground gas pipelines, with the replacement of gas analyzers.

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Persian Abstract

چکیده

در این بخش، یک مدل شبیه سازی نشت خط لوله زیرزمینی ایجاد شد. مدل‌سازی میدان‌های جریان خطوط لوله هوایی و خطوط لوله زیرزمینی با تخلخل‌های مختلف خاک انجام شد. تأثیر محیط زیرزمینی و تخلخل خاک بر میدان نشت خط لوله مورد تجزیه و تحلیل قرار گرفت. تأثیر تغییرات در محیط زیرزمینی و تخلخل خاک بر از دست دادن انرژی جنبشی در نشت گاز تعریف شد. بنابراین، قانون تغییر در ویژگی های سیگنال صوتی نشتی روی دیواره لوله به دست آمد. بر اساس نتایج مطالعه، منطقه آسیب به یک خط لوله گاز تعیین شد که به تناسب قطر جت گاز بستگی دارد. از آنجایی که گاز از یک شکاف در خط لوله گاز و با تخلخل های مختلف مواد لوله آزاد می شود، انتشار گاز رخ می دهد. در نتیجه منطقه انفجار افزایش یافت که در نهایت انتشار گازها در محیط تحت تأثیر فشار افزایش یافت.