

Study on The Attenuation of Acoustic Emission Signals from Plastic Pipes

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Abstract: Buried plastic gas pipelines are widely used and have high safety requirements, so research into leak monitoring techniques has been of considerable interest. This paper combines theoretical and experimental studies of the attenuation characteristics of plastic pipe leakage acoustic emission signals to provide technical support for the use of acoustic emission technology to monitor plastic pipe leakage and failure.

Keywords: Plastic pipes, Attenuation characteristics, Acoustic emission techniques.

1. Introduction

China's urban energy use has entered the era of natural gas, and on 20 May 2021 PetroChina released its 2020 CSR report, which shows that in 2020 PetroChina's domestic natural gas production exceeds 130 billion cubic metres, with natural gas accounting for more than 50% of the oil and gas mix for the first time, while China's overall natural gas production has increased from 27.7 billion cubic metres in 2000 to 188.9 billion cubic meters, an increase of nearly seven times, with an average annual growth of 10%[1]. Plastic pipelines have been widely used in gas transmission and distribution networks in China due to their remarkable characteristics such as chemical resistance, long life, easy construction, good impact resistance, environmental friendliness, easy moulding and processing, and good overall energy efficiency[2]. As most plastic gas pipelines are buried underground in a complex environment, with a long period of time in use, complex and varied pipeline problems often arise with the growth of the pipeline's service life and the ageing of the pipeline, such as chemical corrosion of the internal surface of the pipeline caused by internal media, perforation leakage, weld rupture and deformation caused by welding defects and mechanical damage caused by external interference. The resulting pipeline accidents (poisoning, fires and explosions) can lead to a significant waste of resources, environmental damage and loss of life.

Therefore, for pipeline leakage monitoring and detection is very necessary, acoustic emission method has the advantages of being sensitive to changes in the leakage signal, high localization accuracy, low detection cost and strong adaptability, etc., and is widely used in pipeline leakage detection and monitoring. At present, many experts and scholars at home and abroad use acoustic emission technology to carry out corresponding research on pipeline leaks, Cruz et al[3] proposed acoustic emission sensor combined with machine learning for gas pipeline leak location method, the method can accurately detect small leaks in pipelines with low pressure and external interference, with an accuracy rate of 99.60%; Zhang Xi et al[4] used the attenuation characteristics of acoustic emission waves to propose a broadband acoustic emission source. The three-sensor localization model was used for the noise that could not be completely eliminated to achieve a high localization accuracy at low leakage rates.

As plastic pipes are different from steel pipes for acoustic emission signals have good transferability, plastic materials as viscoelastic polymer materials, acoustic emission signal propagation in plastic media, serious acoustic attenuation and acoustic dispersion will occur, the former so that the acoustic energy with the propagation distance is constantly reduced; the latter due to the different phase velocity of different frequency components in the acoustic signal, the pulse waveform distortion, the acoustic properties of plastic on the acoustic waveform. The influence of the acoustic properties of plastic on the acoustic waveform accumulates with the increase of the propagation distance[5], so to understand the plastic pipe leakage acoustic emission signal attenuation characteristics of the changing law in order to use it in the process of plastic pipe leakage monitoring.

2. Theoretical Analysis of Acoustic Emission Attenuation

Studies in the literature have shown that the amplitude of the acoustic emission signal from plastic pipes decays approximately according to the exponential law as the propagation distance increases, and the amplitude decays with propagation distance as shown in equation (1) [6]:

$$U_L = U_o e^{-\alpha L} \quad (1)$$

Where: U_o is the initial amplitude; U_L is the amplitude at a distance L from the wave source; α is the attenuation coefficient of the medium.

The three main causes of acoustic signal attenuation in practice are diffuse attenuation, absorption attenuation and scattering attenuation:

$$\alpha = \alpha_d + \alpha_a + \alpha_s \quad (2)$$

Where: α_d is the diffusion attenuation coefficient; α_a is the absorption attenuation coefficient; α_s is the scattering attenuation coefficient.

Diffusion attenuation means that the acoustic emission wave propagates in all directions and the energy therefore spreads in all directions, but for gas pipeline acoustic emission wave propagation in uniform pipe wall can be seen as a plane wave, thus there is no diffusion attenuation[7],

equation (2) can be simplified as:

$$\alpha = \alpha_a + \alpha_s \quad (3)$$

Absorption attenuation coefficient α_a :

$$\alpha_a = \frac{2\pi f^2}{\rho v_l^3} \frac{\chi}{C_V} \frac{E^\sigma - E^\theta}{E^\theta} \quad (4)$$

Where: ρ is the density of the pipe material, kg/m^3 ; f is the frequency of the acoustic emission signal, Hz ; v_l is the longitudinal wave velocity of the acoustic emission, m/s ; C_V is the constant specific heat capacity of the pipe, $J/(kg \cdot k)$; χ is the heat transfer coefficient of the pipe, $W/(m \cdot k)$; E is the corresponding elasticity factor, MPa .

Scattering attenuation coefficient α_s :

$$\alpha_s = \frac{8\pi^4 L_c^2 f^4}{9v_l^4} S \quad (5)$$

Where: L_c is the average grain diameter of the pipe material, m ; S is the scattering factor, is a function of the incident and scattered waves [8].

Simplifying other types of attenuation such as dispersion, "leakage" between adjacent media and obstructions to α' makes the attenuation model more relevant to real world situations and has engineering applications:

$$\alpha = \alpha_a + \alpha_s + \alpha' \quad (6)$$

In the actual propagation process, the attenuation mechanism of acoustic emission waves is very complex and difficult to establish a perfect theoretical model, the attenuation coefficient is very difficult to find, must be based on theoretical research to find the experimental. The size of the attenuation coefficient of acoustic emission is related to the range of acoustic emission sensors and is a key factor in the effectiveness and efficiency of monitoring in the process.

3. Experimental Analysis of Acoustic Emission Attenuation of Plastic Pipes

Based on theoretical analysis of the attenuation of acoustic emission signals from leaks in plastic gas pipelines, a complete plastic pipeline system is built in a laboratory environment, using an air compressor to fill the pipeline with high-pressure air to simulate gas transport, and by opening artificial leak holes in the pipeline, a leakage failure simulation experiment is carried out to study the attenuation of acoustic emission signals from plastic gas pipelines at different distances and pressures.

With the internal pressure of the pipe kept constant and the leak hole diameter of 4mm, the distance of the sensor from the leak hole is varied and the signal is collected at 0.0m, 0.1m, 0.2m, 0.3m, 0.4m, 0.5m, 0.6m, 0.7m, 0.8m, 0.9m, 1m, 2m, 3m, 4m, 5m, 6m, 8m, 10m, 12m, 18m and 26m in turn. Pipeline leakage signal amplitude and analyse its attenuation change pattern.

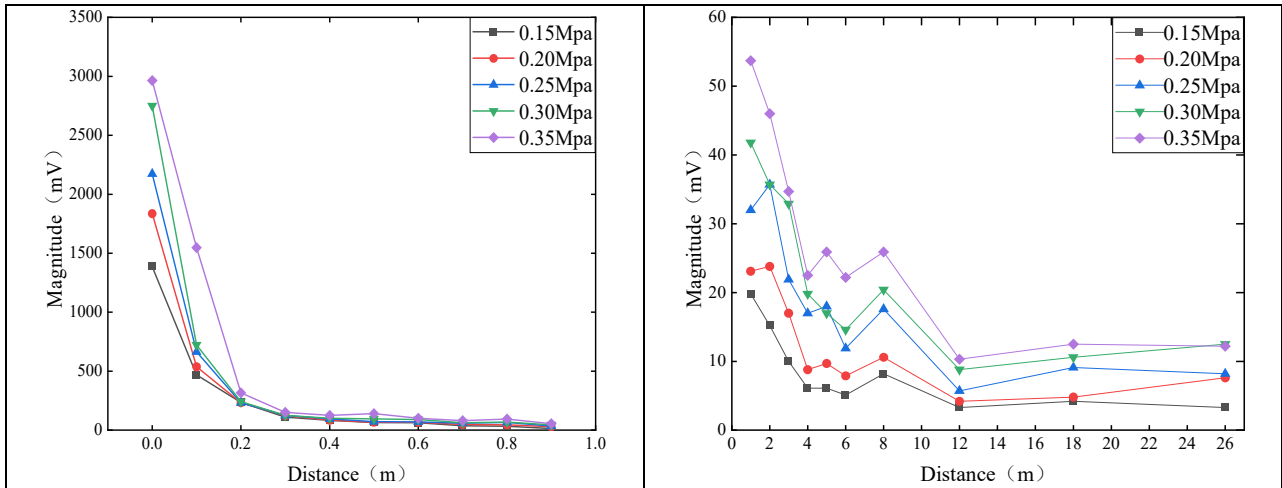


Figure 1. Leakage signal amplitude versus distance

As the monitoring distance increases, the amplitude of the acoustic emission signal of the pipeline leakage decreases rapidly in the near distance, and it has decayed to a small value at 0.2m~0.3m with little change afterwards. As the propagation distance gradually increases, the acoustic emission signal attenuates very seriously, with a large attenuation coefficient, and the amplitude image conforms to the form of an exponential function; the anomalous increase at 8m and 26m is due to the mode conversion that occurs during the propagation of the acoustic emission wave, as the sharp pulse waves generated by the wave source propagate, the waves of different modes propagate at different speeds, so that different types of waves arrive in turn and superimpose

or cancel each other, making the amplitude As the propagation distance increases, the amplitude does not show a monotonic decline; the greater the leakage pressure, the greater the amplitude of the leakage acoustic emission signal, the different leakage pressure attenuation characteristics of the law of change has the same trend, that is, the attenuation characteristics and the size of the leakage pressure is not relevant.

4. Summary

(1) The attenuation of acoustic emission signals from plastic pipe leaks at different pressures is very serious, and the

overall attenuation image is in the form of an exponential function, basically decaying to a minimal value at 0.2m~0.3m, with subsequent fluctuating attenuation trends.

(2) The amplitude of the acoustic emission signal at longer distances does not simply decrease but shows a fluctuating trend and an anomalous increasing point, which is due to the fact that the acoustic emission signal undergoes a certain degree of mode shift during transmission, and the waves of different modes propagate at different speeds and superimpose on each other, resulting in an anomalous increasing point.

(3) The higher the pressure, the greater the amplitude of the acoustic emission signal, but its attenuation change law has nothing to do with pressure, different pressure have the same change in attenuation change law, that is, the attenuation characteristics and the size of the leak pressure.

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