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Integrated-signal-based leak location method for liquid pipelines

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ABSTRACT

Leaks in pipelines can cause major incidents resulting in both human injuries and financial losses. Among the considerable leak detection and location methods, the Negative Pressure Wave (NPW) based method has been widely used in locating leaks in liquid pipelines. The NPW based method only monitors the pressure changes at two ends of a pipeline. But the pressure is apt to be fixed by the end equipment and the change of it induced by a small or slow leakage is too small to be detected, which limit the application of the NPW based method in these situations. This paper presents a novel leak location method based on integrated signal, which is a combination of the pressure and flow rate signals. The representation of the integrated signal is derived from the transient analysis of the leakage. For the change of the integrated signal induced by a leakage is larger than the pressure change and it is also unaffected by the end equipment, the proposed method can be used to detect and locate small or slow leakage in a pipeline and can also be used in pipelines which end pressures are fixed by some kinds of equipment. The validation of the proposed method also confirms its advantages.

1. Introduction

Pipelines are important means of transporting petroleum products. Thus, leakage surveillance is important in pipeline management for safety and environmental reasons and for the development and usage of leak detection and location systems, which fall into three categories: visual inspection, externally based methods, and internally based methods. Externally based methods detect leaks via fiber optic or dielectric cables installed along pipelines, whereas internally based methods use instruments to monitor internal pipeline parameters such as pressure, flow rate, or temperature at pipeline ends and use these parameters to infer leakage by computation. Internally based methods can also be classified as acoustic based methods (Liang et al., 2013), negative pressure wave (NPW)-based methods, model-based methods (Reddy et al., 2011), and transient-based methods (Andrew et al., 2009). Each approach has its corresponding strengths and weaknesses. The most commonly used method is the NPW-based method because of its relatively low cost, easy implementation, acceptable detection sensitivity, and location precision.

The fundamental principle of the NPW-based method is as follows. The occurrence of a leak causes a rapid pressure drop at the leakage point; NPW forms and travels with acoustic velocity from the leakage point to the inlet- and outlet-ends of the pipeline, thus changing the pressure at both ends. The pressure changes are measured by pressure sensors installed at the two pipeline ends and identified by a certain mathematical method. The leakage location is calculated by transferring the acoustic speed of the NPW and the difference in arrival time of the NPW at both ends. Fig. 1 illustrates the typical structure of NPW-based leak detection and location systems. The pressure sensors and flow meters installed at both pipeline ends measure the pressure and flow rates, respectively. The pressure is used to locate the leakage point, whereas the flow rates are used to detect the leakage according to the difference between the inlet and outlet flow rates.

The key point of the NPW-based method is the identification of the sudden pressure drop in the measured pressure signals. The pressure drop should be sharp and large enough because the NPW-based method has some limitations in detecting slow or small leaks. However, in most cases, the pressure changes induced by a leak are not only related to the size and location of the leakage but are also affected by the terminal equipment (Sun et al., 2010). For extreme situations, a tank connected to the outlet end of the pipeline or a pressure control system equipped at the inlet end will fix the inlet or outlet pressure at a certain value and significantly mitigate pressure changes.

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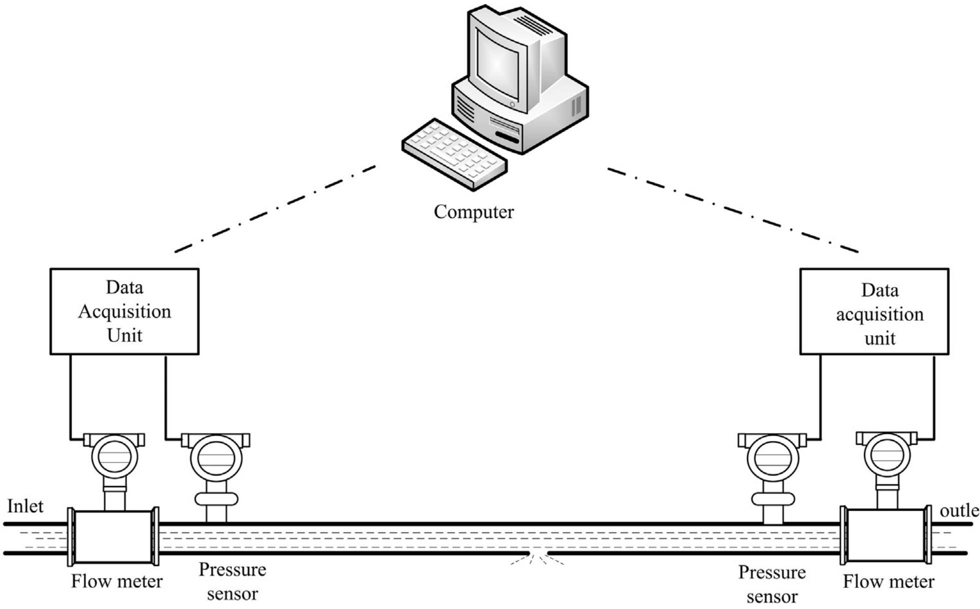

Fig. 1. Structural diagram of the leak detection system.

Considerable research has been conducted to analysis the pressure drop detected at pipeline ends. Ge et al. (2009) investigated the use of wavelet transforms in identifying the sharp transition in pressure signals. Zhang et al. (2014) designed a dynamic pressure transmitter to obtain high detection sensitivity and leak resolution, and Guo et al. (2008) proposed a pre-filter to denoise the pressure signals for the next step in the leak location process. However, studies have not investigated whether the flow rates at the ends can serve as leaking features similar as pressures in leak location.

Flow rate or fluid velocity changes propagate along the characteristic lines at the speed of sound depending on the method of characteristics (MOC) (Bruce et al., 1999). The same phenomena can be observed in experiments in previous literature (Bajoraitytė and Bogdevičius, 2003) and in our leakage data collected from pipelines in the field. These findings have motivated us to investigate the generation and propagation of the release transient process.

This paper is organized as follows. Section 2 presents the investigation of the release transient process and introduces the proposed integrated-signal-based method. Section 3 demonstrates the application of wavelet transform in identifying the singularity in signals. Section 4 shows the validation of the proposed method. Section 5 concludes.

2. Detection principle

2.1. Governing equation of pipeline and numerical simulation

The relationships that describe a fluid flowing through a pipeline are obtained by applying the mass and momentum conservation laws. Assume that a straight, horizontal pipeline segment has a constant circular internal diameter D transited by an incompressible fluid with density ρ. The governing equations of the system can be written in SI units as follows (Wylie et al., 1993):

$$\frac{\partial w}{\partial x}+\frac{1}{\rho a_S^2}\frac{\partial p}{\partial x}=0, \tag{1}$$

$$\frac{\partial w}{\partial t}+w\frac{\partial w}{\partial x}+\frac{1}{\rho}\frac{\partial p}{\partial x}+\frac{\lambda}{2D}w^2=0, \tag{2}$$

where w and p are the velocity and pressure of the fluid as a function of time t and distance x, respectively; λ is the coefficient of friction; a_s is the speed of sound in the fluid.

The MOC is the most general and widely used technique for solving these equations. By using MOC, the conservation equations in Eqs. (1) and (2) can be replaced by two compatibility equations along their corresponding characteristic lines (C^+ and C^-, respectively). C^+ and its compatible equations are expressed as follows:

$$\frac{dx}{dt}=a_S, \tag{3}$$

$$\frac{dp}{dt}+\rho a_S\frac{dw}{dt}=\frac{-\lambda\rho a_S w|w|}{2D}. \tag{4}$$

C^- and its compatible equations are expressed as follows:

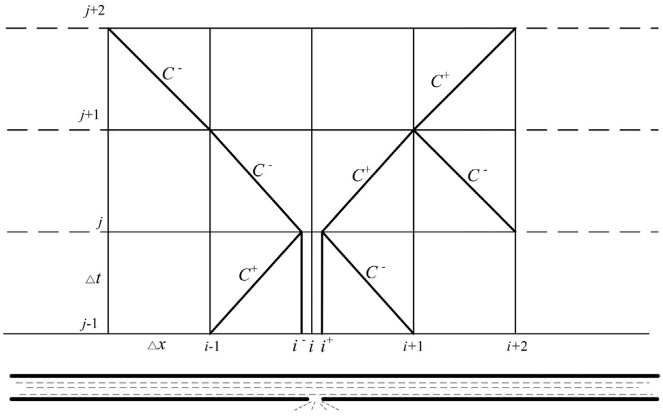

Fig. 2. Generation and propagation of release transient information.