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An improved method of soil-gas sampling for pipeline leak detection: Flow model analysis and laboratory test

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ABSTRACT

A flow model is presented in this short communication to design a horizontal sampling method of soil-gas for pipeline leak detection. The soil-gas flow model is verified by air-extraction tests. A laboratory method is also designed in this short communication to evaluate the effective detection radius of organic volatile compounds (VOCs) using the horizontal sampling method. Results of laboratory tests demonstrate that the effective detection radius using the horizontal sampling method for pipeline leak detection is at least 30 m and 20 m for gasoline and diesel, respectively.

Contents

1. Introduction

Pipeline leaks of gasoline and diesel represent one of the most common environmental problems in shallow aquifers contaminated with petroleum hydrocarbons liquids. The leak sources continue to dissolve into aquifers as active sources of groundwater contamination (Kim and Corapcioglu, 2003; Kuo et al., 2016). It is essential to detect pipeline leaks as early as possible. This short communication presents a soil-gas flow model to design an improved sampling method of soil-gas for pipeline leak detection.

Soil-gas techniques have been used to survey leaks of organic volatile compounds (VOCs) from underground storage tanks and pipelines (Kerfoot and Mayer, 1986; Marrin and Thompson, 1987; Thompson and Marrin, 1987; Marrin and Kerfoot, 1988; Liang and Kuo, 2006). Traditional soil-gas method installs vertical probes in the vadose zone to take gas samples. The effective sampling radius of a vertical soil-gas probe is only around 5 m (Liang and Kuo, 2006). Therefore, a large quantity of vertical probes and gas samples are required to conduct a soil-gas survey for a long-distance pipeline. An improved sampling method of soil-gas was proposed by Liang and Kuo (2006) to enhance the effective radius of soil-gas

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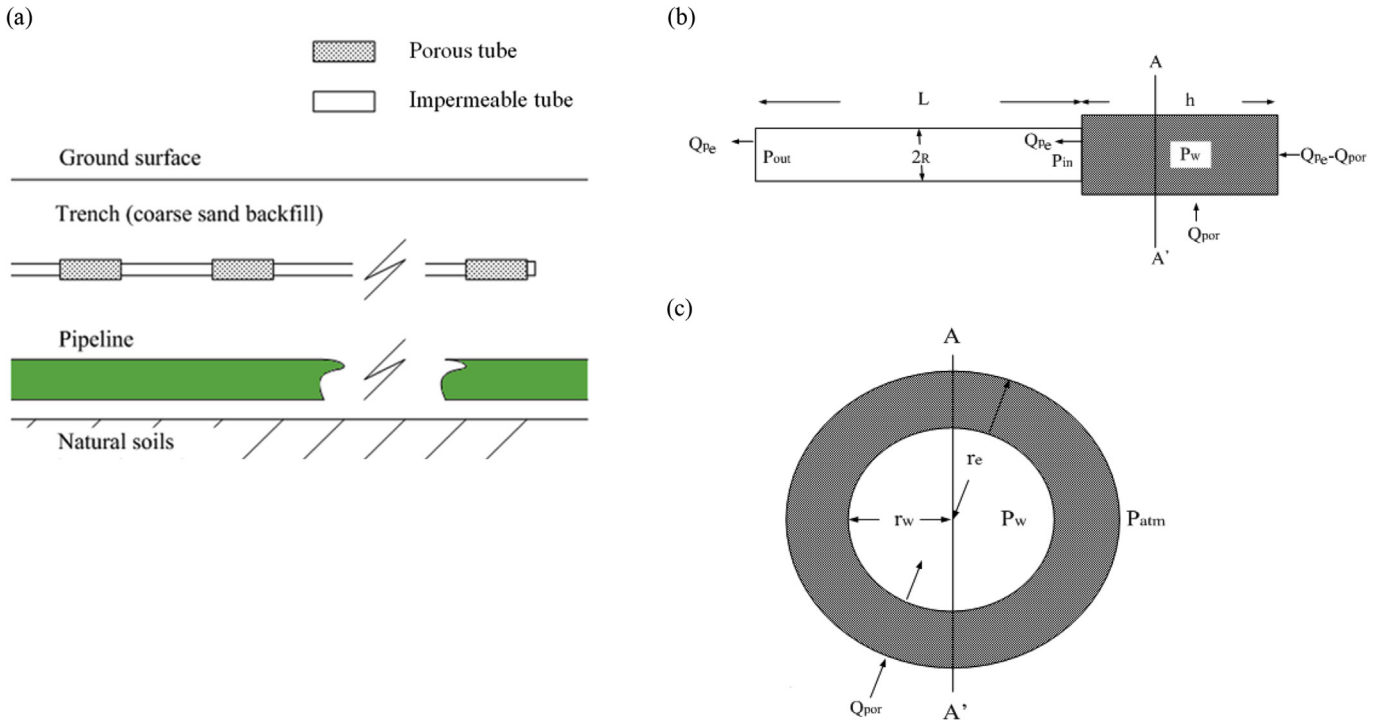

Fig. 1. An improved method of soil-gas sampling. (a) Schematic diagram of pipeline leak detection. (b) A basic section unit. For Q_{pe}, see Eqs. (2) and (4) in text. (c) Cross section of a porous probe. For Q_{por}, see Eq. (3) in text. (from Liang and Kuo, 2006).

sampling for pipeline leak detection. Fig. 1a shows the improved sampling method which is a horizontal sampling line of soil gas running above and nearby the pipeline. The horizontal sampling line consists of intermittent porous sampling probes connected in series.

To design the improved method of soil-gas sampling for pipeline leak detection, a mathematical model is required to predict the flow distribution of soil-gas through each porous probe in the horizontal sampling line. An incorrect derivation of flowing pressure was found in the soil-gas flow model presented by Liang and Kuo (2006). One can refer to Fig. 1b for the materials balance and mathematical symbols used in the above-mentioned equation as follows.

$$P_{out,next\quad section} = P_w + \frac{Q_{por}}{Q_{pe}}(P_{atm} - P_w) \tag{1}$$

Liang and Kuo (2006) assumed that the pressure drop between the inlet and center of the porous tube was negligible. Originally, this assumption was thought not to be serious. However, the value of gas viscosity at 20 °C and 1 atm absolute used in their model calculations ($\mu = 0.07$ cp) had to be notably higher than the literature value ($\mu = 0.012$ cp, McCabe and Smith, 1976). In this short communication, the above-mentioned assumption is removed from the soil-gas flow model. The revised model predictions are also verified with experimental data obtained from air-extraction tests. Currently, experimental data using the above improved sampling method for soil-gas is scarce in the literature. A laboratory method is designed in this short communication to evaluate the effective detection radius of VOCs for the horizontal sampling method. The objectives of this short communication were to (1) present a soil-gas flow model to design the horizontal sampling method, (2) verify the soil-gas flow model using air-extraction tests, and (3) evaluate the effective leak-detection radius of VOCs for the horizontal sampling method by the laboratory method.

2. Materials and methods

2.1. Description of horizontal soil-gas sampling method

The improved sampling method is a horizontal sampling line of soil gas running above and nearby the pipeline (Fig. 1a). The sampling line is made up of intermittent porous sampling probes connected in series by impermeable flow lines. Fig. 1b shows a basic section unit consisting of a porous sampling probe and an impermeable flow line. The specifications of materials used for constructing the horizontal sampling line of soil gas in this study are as follows. Each impermeable flow line is a polyethylene tube 100 cm long with an outside and inside diameter equals to 1.2 cm and 0.9 cm, respectively. Each porous sampling probe made from rubber is 5 cm long with an outside and inside diameter equals to 1.6 cm and 1.2 cm, respectively. The measured permeability of the porous sampling probes used in this study is 0.0619 ± 0.0095 Darcy.

2.2. Laboratory leak-detection tests

Fig. 2 shows the schematic diagram of the laboratory leak-detection experiment with a sampling line. One end porous probe of the sampling line is installed inside a glass column above a reservoir of gasoline or diesel. At the other end of the sampling line, an extraction pump is employed to take soil gas samples with Tedlar bag in a vacuum box. The glass column is backfilled with coarse sands. The permeability of backfill using coarse sands (in the order of 100 Darcy) is much greater than that of the porous tubes. The high-permeability backfill allows sufficient soil-gas to flow through each porous tube during soil-gas extraction.

Each leak-detection experiment starts with a fresh column of coarse sands and a cleaned detection system either 20-m or 30-m long. Background soil-gas samples are taken before filling the reservoir with gasoline or diesel. After taking the background