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Leak detection in gas pipeline networks using an efficient state estimator. Part II. Experimental and field evaluation

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ABSTRACT

In Part-I of this two part paper, a method is proposed for on-line leak detection and identification in gas pipeline networks using flow and pressure measurements. Simulations on two illustrative networks were used to demonstrate the applicability of the proposed method. In this paper, the performance of the proposed leak detection and identification methodology was evaluated using experiments with compressed air on a laboratory scale network. The on-line applicability of the proposed methodology was demonstrated through field level leak detection tests carried out on a 204.7 km long pipeline in India, supplying natural gas to a power plant. The laboratory and field tests demonstrated that the proposed methodology can be used for quick on-line detection of leaks, and locating the leaks reasonably accurately.

1. Introduction

On-line leak detection of leaks caused by ruptures in cross-country and urban pipeline systems carrying natural gas and other petroleum products is very important from the point of view of safety, environment and economic considerations. Leak detection methodologies can be broadly classified into hardware based and software based systems. Hardware based leak detection systems include pigging, acoustic methods, tracer gas methods, sensor cable method, fiber optic methods, infrared photography methods and radar methods. Although hardware based leak detection systems often provide very accurate leak location, they are expensive, difficult to install, and many times are used only periodically to test the integrity of the pipeline (Geiger, Werner, & Matko, 2003). In contrast, software based solutions allow continuous on-line monitoring and rapid detection of leaks. However, a survey by Scott and Barrufet (2003) concluded that many software based leak detection systems are marketed as “black boxes” and there is a need for verification and demonstration of capabilities of these methods.

In Part-I of this two part paper (Reddy, Narasimhan, Bhallamudi, & Bairagi, 2011), a reliable and computationally efficient method for detection and identification of leaks in gas pipeline networks was proposed. The proposed method uses the available pressure and flow rate measurements, sampled at regular intervals and is based on an efficient state estimation technique. Performance of the proposed methodology was evaluated using simulations on two illustrative pipeline systems. The effect of measurement noise and the redundancy in the availability of measured data on the performance of the method was also studied. In this paper, the proposed methodology is evaluated using experimental data obtained on a laboratory scale model and operating data obtained from tests conducted on a real life pipeline carrying natural gas.

Although there have been several experimental and field studies for evaluating leak detection methodologies for liquid pipelines (Brunone & Ferrante, 2002; Liou & Tian, 1995; Silva, Buiatti, Cruz, & Pereira, 1996; Souza, Cruz, & Pereira, 2000), relatively fewer experimental and field studies for gas pipelines have been reported. Watanabe and Himmelblau (1980) conducted leak tests on a laboratory scale gas pipeline for validating an acoustic based leak detection technique. Billmann and Isermann (1987) have reported a field study on a 150 km long gas pipeline. Pressures and flows were measured at both ends of the pipeline and a model based technique for leak detection was evaluated. Fukushima, Maeshima, Kinoshita, Hitoshi, and Koshijima (2000) implemented a leak detection method, based on a dynamic simulation with wave equations, on the 250 km long Niigata-Sendai pipeline. In their evaluation tests, pressures and temperatures were measured at valve stations, located at 12 km intervals, and flow rate of gas was measured at

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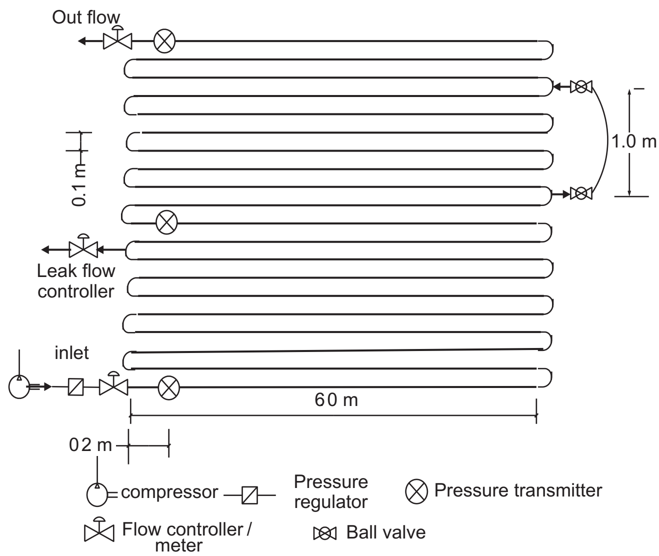

Fig. 1. Schematic of the laboratory experimental setup.

inlet and outlet of the pipeline. The purpose of the present study is to evaluate the leak detection methodology proposed by the authors using extensive laboratory and field studies. Furthermore, the laboratory studies include tests on a single pipeline as well as a simple gas pipeline network. Field studies include both off-line and on-line tests.

2. Laboratory experiments

2.1. Set up

The schematic of the laboratory experimental set up is shown in Fig. 1. It consisted of 60 two-meter length tubes connected in series to make a 120 m pipeline. It had provision for one interconnecting limb between two nodes of the main pipeline to form a simple network. Leak proof rigid acrylic coupling joints were used to connect two-meter long tubes. Every 6 m length segment of the pipeline (3 m × 2 m tubes) was connected to the neighboring segments by U-bends, with a leak proof flange joint, which facilitates ease in reconfiguration of the network. The experimental set up was vertically mounted, with a distance of 10 cm between centre lines of two neighboring pipes. Compressed air was used as the fluid in this experiment. Leaks were created (one at a time) at a predetermined junction between two 6 m segments by replacing the normal U-bend with a special U-bend, which was connected to a flow controller (Fig. 1). This flow controller was used for releasing air from the tube into the atmosphere at a specified flow rate. The instrumentation for data logging and flow control is also indicated in Fig. 1.

2.1.1. Pipeline

The pipeline was made of Perspex tubes, each 2 m long, 12 mm ID, and 18 mm OD (3 mm thick). A sample Perspex pipe was tested for its strength. It was found that the pipeline can withstand an internal pressure up to 12 kg/cm^2. Therefore, experiments were conducted such that the maximum pressure in the experiments did not exceeded 5 kg/cm^2.

2.1.2. Compressor

A tank type reciprocating compressor [AirEquip, Chennai] which can give a maximum pressure of 12 kg/cm^2 was used to pump air into the system. The tank type compressor switches on at 5 kg/cm^2, and switches off at 7.5 kg/cm^2. The tank size was 160 l. It could deliver free air at a maximum flow rate of 400 LPM continuously at 3.0 kg/cm^2 pressure. The air on delivery was at the room temperature. A manual pressure regulator was used on the delivery side of the compressor to regulate the pressure of inlet air to the pipeline. The regulator was set to give a delivery pressure of 4.0 kg/cm^2 or less.

2.1.3. Pressure sensors

Three pressure sensors were used to monitor the pressures at different locations in the pipeline. These pressure transmitters were located at distances 0.0 m (near the inlet to the pipeline), 61.85 m from the upstream end, and 124.35 m (almost at the exit) from the upstream end. The pressure sensors were of Tecsis make (Forbes Marshall).

2.1.4. Mass flow meter/controllers

Two mass flow meter/controllers (Cole Parmer, United States) were used at the upstream and downstream ends of the pipeline to measure and control the flow rate in the pipe line. The mass flow controller/meter at the upstream end was used only for measuring the mass flow rate. The mass flow controller/meter at the downstream end was used for controlling as well as measuring the flow rate. Flow controller cum flow meter works in the range of 2.5–250 SLPM (standard liters per minute).

One mass flow controller/meter (Cole Parmer, United States) with flow rate range of 0–30 SLPM was used to simulate the leak at any pre-specified leak location. This controller was mounted in such a manner that it released the air from the pipeline to the atmosphere. It may be noted that only one leak at a time was simulated in all the tests.

2.1.5. Miscellaneous

A data acquisition system (DAS) was used to automatically record all the pressure and mass flow measurements as well as to control the mass flow controllers. Flow rates and pressures were sampled at 100 ms intervals.

2.2. Procedure

Initially, calibration runs, without leak, were made and the collected data for pressures and mass flow rate were used to determine the roughness height, ε for the Perspex pipe. For this purpose, the measured flow rates, and the measured pressures were used in the state estimation model and the roughness height was determined such that the difference between the estimated and the measured flow variables was minimum.

The experimental procedure followed in leak detection tests is described below:

1. The compressor outlet pressure was set at a particular value.
2. Initially at time t = 0.0 s, the mass flow controller inducing the leak (Fig. 1) was kept in completely closed position.
3. The outlet mass flow rate controller was set to give a specified mass flow rate.
4. Pressures at three locations and mass flow rates at the inlet and the outlet were recorded through the DAS at every 0.1 s sampling interval.
5. After a time t, the mass flow controller inducing the leak was opened instantaneously (step change) to allow a controlled leak thereafter.
6. Pressure and flow rate measurements were continued for more time after the leak was induced.
7. The above procedure was followed for more test runs by varying (i) the upstream pressure, (ii) the initial mass flow rate, (iii) the leak magnitude, and (iv) the leak location. Experiments were