PRESSURE-BASED LEAKAGE CHARACTERISATION OF BULK SUPPLY PIPELINES

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ABSTRACT

Leakage from bulk pipelines has not received much attention in the research literature due to the difficulty of measuring it. However, recent developments in understanding the behaviour of leaks with changes in pressure have created opportunities for cost-effective field-based leakage characterisation. Field and laboratory studies have shown that leakage from water pipelines is substantially more sensitive to pressure than conventionally believed. It has now been established that the major cause of this phenomenon is that the areas of leaks are not static but vary linearly with pressure. The aim of this study was to determine the characteristics and extent of water losses on a number of bulk water pipelines in South Africa. The study used a specially designed device in combination with the latest models of leak area behaviour. Test pipes were first isolated and then pressurised using an external pump and water source. Measuring the leakage rate at different pressures allowed the leakage area to be estimated as a function of pressure. The study showed that the proposed method provides an efficient, non-intrusive and cost-effective way to characterise the leakage condition of bulk pipelines.

KEYWORDS

Bulk water pipelines; Leakage; Field tests

PRESENTER PROFILE

Kobus van Zyl holds a Ph.D. from the University of Exeter. He was employed at the Universities of Johannesburg and Cape Town before recently joining the University of Auckland as the Watercare Chair in Infrastructure. Kobus is a Professional Engineer and an Associate Editor of the ASCE Journal of Water Resources Planning and Management. He is Past-Chair of the ASCE standing committee on Water Distribution Systems Analysis and a member of the EPANET Visioning Task Committee. His research interests include hydraulic modelling, the behaviour of leaks in pipes, smart infrastructure and resilience.

1 INTRODUCTION

Leakage from water supply systems is a significant problem world-wide, with some systems losing as much as 50 % of the water entering them in this way (EU, 2015). New leaks continuously appear as water supply systems deteriorate with age and thus regular condition assessment is essential to manage this problem.

Several international guidelines have been published on leakage management in water supply systems, including recent documents by the European Union (EU, 2015) and the American Water Works Association (AWWA 2016). While detailed guidelines for leakage assessment and benchmarking are provided for distribution networks, bulk supply pipelines have received little attention.

Leakage assessment techniques for bulk pipelines are often slow and expensive processes that may include significant disruption to the supply. Common leak detection techniques include external noise correlators, ground penetrating radar, electrical resistivity tomography, inline acoustic sensors and satellite imagery.

The purpose of this study was to apply a novel pressure-based method to characterise leakage in a range of bulk pipelines in South Africa. The method pressurised an isolated pipe section to different levels to assess their leakage response to variations in pressure. The results were then interpreted using latest understanding of leakage behaviour to identify the size, type and possible location of leaks. The method is efficient, cost-effective and requires minimal interruption to the operation of the pipeline.

2 THEORETICAL BACKGROUND

Hydraulically, leaks are orifices and should adhere to the orifice equation, which is derived from the conservation of energy principle. According to the orifice equation, the leakage flow rate Q through a leak with area A is given by:

$$Q = C_d A \sqrt{2gh} \quad (1)$$

Where C_d is the discharge coefficient, g gravitational acceleration and h pressure head.

However, several field and laboratory studies (Ogura 1979; Hiki 1981; Lambert 2001; Farley and Trow 2003) have showed that leakage from water distribution systems do not adhere to the orifice equation, which led leakage practitioners to adopt a power equation in the form:

$$Q = Ch^{N1} \quad (2)$$

Where C is the leakage coefficient and $N1$ (also known as α) the leakage exponent. A number of studies investigated this behaviour (Van Zyl & Clayton 2007; Schwaller & Van Zyl 2014; Walski *et al.* 2006; Van Zyl *et al.* 2013), concluding the main reason for the discrepancy to be that leak areas are not fixed as assumed in the orifice equation, but vary linearly with pressure (Greyvenstein & Van Zyl 2007; Cassa and Van Zyl 2013; Van Zyl and Cassa 2014; Ssozi *et al.*, 2016; Van Zyl & Malde 2017).

The leak area can be represented by linear equation in the form:

$$A = A_0 + mh \quad (3)$$

Where A_0 is the initial leak area and m the head-area slope. Substituting this equation into Equation (1) results in (May 1994; Cassa *et al.* 2010):

$$Q = C_d \sqrt{2gh}(A_0 h^{0.5} + mh^{1.5}) \quad (4)$$

The head-area slope is a function of the leak type and size, pipe material and pipe section properties. Values for the head-area slope have been evaluated and proposed by a number of studies (Cassa & Van Zyl 2013; Van Zyl & Cassa 2014; Van Zyl & Malde 2017; Nsanzubuhoro et al. 2016).

Given the above understanding of leakage behaviour, it is now possible to estimate the size and type of a leak in a pipeline if its leakage response to changes in pressure is measured. Since the area response to pressure is linear, this characterisation can be applied to pipes with one or many leaks.

3 METHODOLOGY

Nsanzubuhoro *et al.* (under review) developed the equipment used in this study and shown in Figure 1. It consists of a 1000 L water tank mounted on a trailer, variable speed pump, pressure and flow sensors and a data logger.

Figure 1: Pipe condition assessment equipment

Once the device is delivered to the test site, it is connected to an access point on the test pipe with a 10 m long, 50 mm diameter flexible hose. After filling the tank, the test pipe is isolated from users and the rest of the system. The pump is then switched on to deliver water from the tank into the pipeline. Since the pipe has been isolated, the pipe leakage can be measured as the water entering the pipe from the device. The pump speed is varied in steps to obtain a range of stable flow and pressure points, and the data analysed to determine the pipe's leakage characteristics.

A total of 15 pipe sections were tested in different parts of South Africa, covering a large range of pipe diameters (50 to 600 mm), lengths (247 m to 9.4 km), longitudinal elevation differences (3.5 to 190 m), ages (less than 10 to over 40 years), drivers (pumped and gravity fed) and locations.

4 RESULTS AND DISCUSSION

One of the pipe tests is discussed in detail as an example to explain the methodology and data analysis, after which the results of all the tests are presented.

The example test conducted on a test near Cape Town on a section of pipe with length 5.4 km, diameter varying from 75 to 50 mm and consisting of asbestos cement, steel and uPVC sections as shown in Figure 2. The pipe was connected to a main supply line (at point V2 in Figure 2) rising continuously to a dead end (point V1 in Figure 2) 190 m above the starting point.

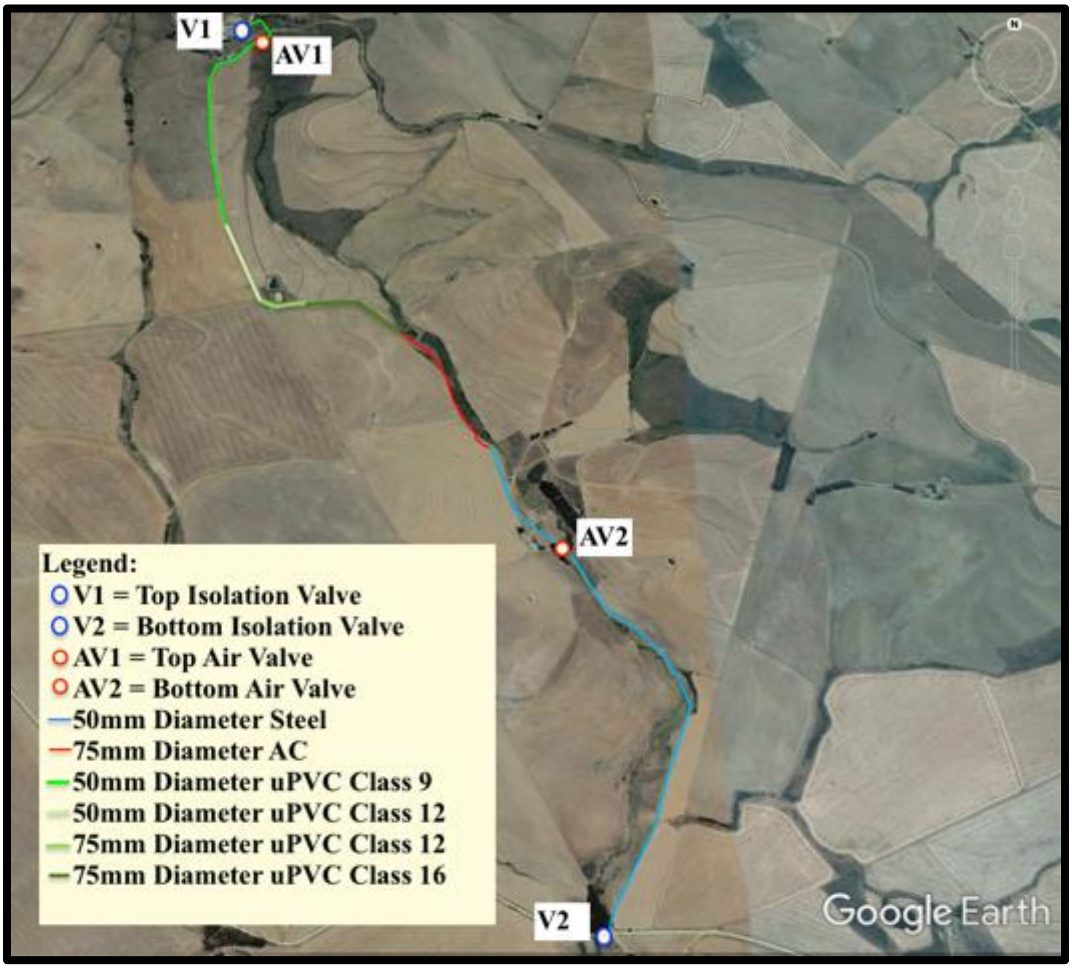

Figure 2: Example test pipe layout

The device was connected to an air valve at the top of the pipe, marked as AV1 in Figure 2. After filling the tank and then isolating the pipe, the device was used to pressurise the pipe to different levels as shown in Figure 3. The flow in Figure 3 indicates a leak on the pipeline that followed a pattern similar to that of the pressure.

The pressure readings in Figure 3 were taken on the device at the top of the pipe and thus don’t represent the pressures at other points along the pipe. Three points were selected to represent the top, centre and bottom of the pipe and the corrected pressure at these points was estimated by taking elevation differences and head losses into account. The resulting leakage flow and pressure at the top, centre and bottom of the pipe are shown in Figure 4.

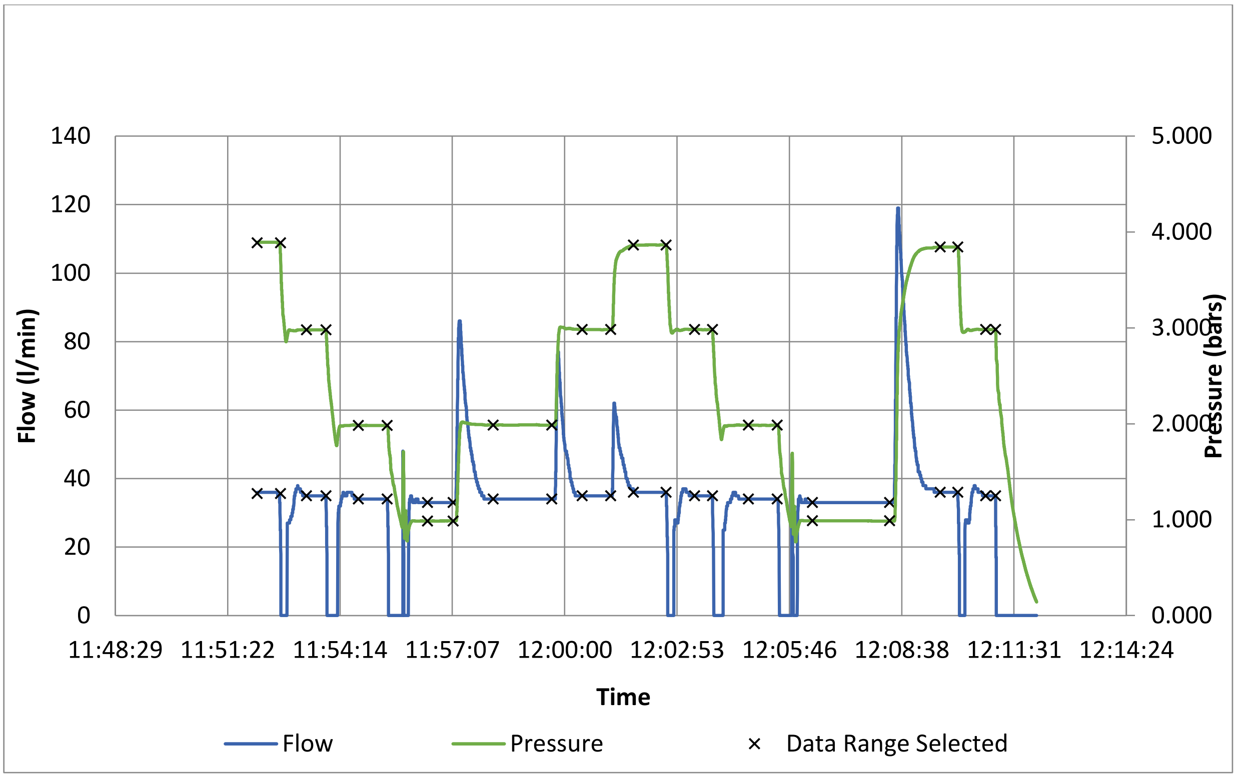

Figure 3: Measured pressure and flow for the example pipe test

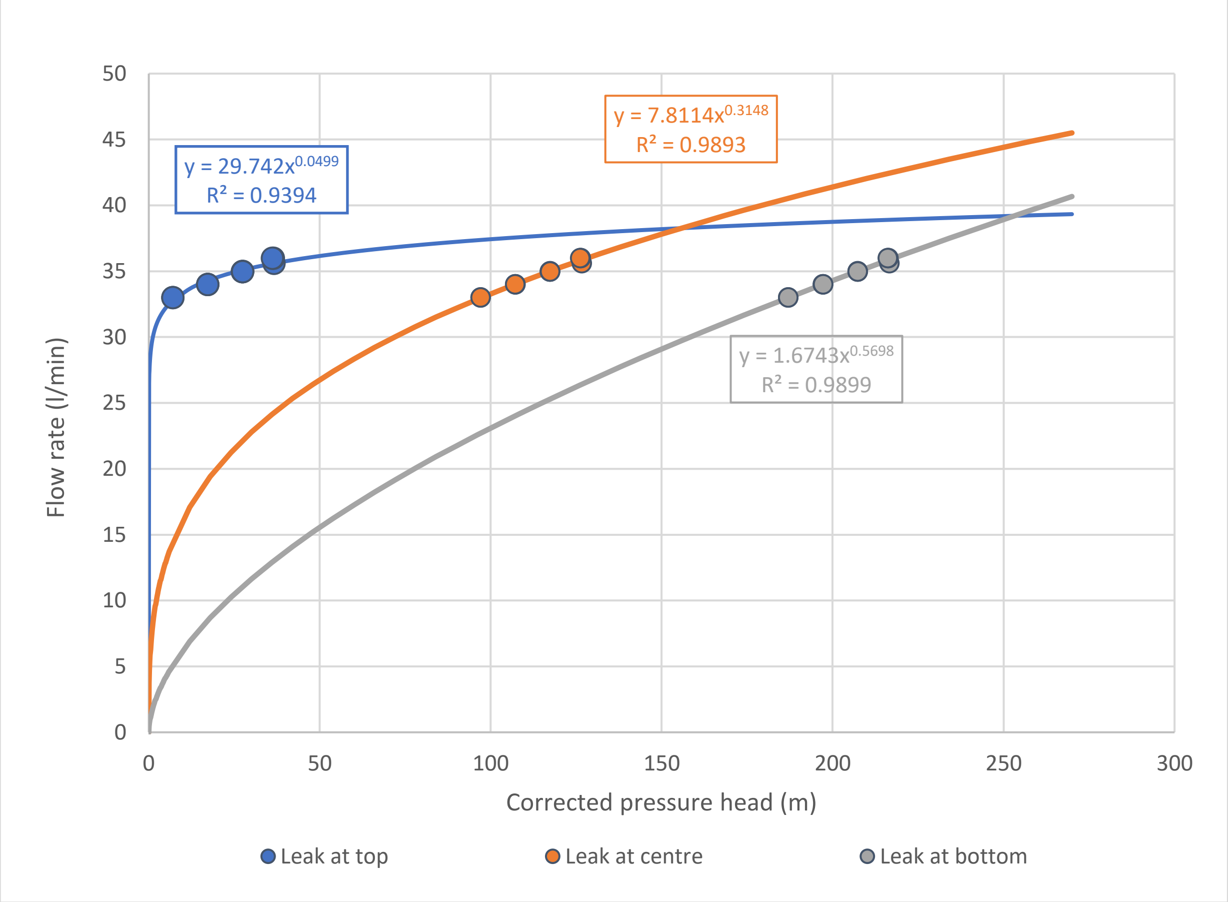

Figure 4: Leakage flow against corrected pressure for three different points on the example test pipe

Power curves were fitted to the data for the three points giving N1 values (from Equation 2) of 0.05, 0.31 and 0.57 respectively at the top, centre and bottom of the pipe.

The effective leakage area ($C_d A$) for each point was then calculated using Equation 1 and plotted against the corrected pressure head as shown in Figure 5.

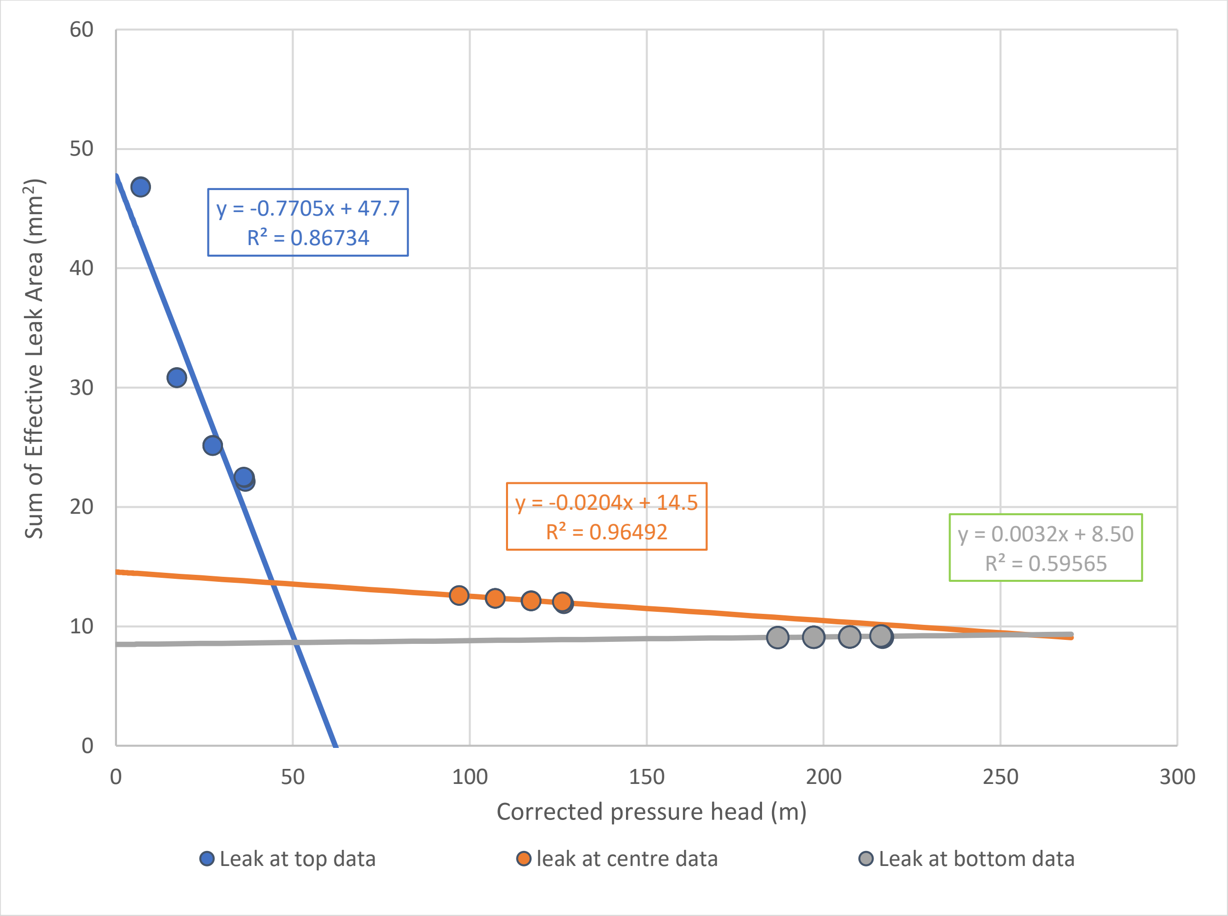

Figure 5: Effective leak area (C_dA) against corrected pressure for three different points on the example test pipe

It is clear from Figure 5 that the leak area varies linearly with pressure. The slope of this line is negative for leaks at the top and centre of the pipe, which implies that the leak area decreases with increasing pressure. While this is possible for circumferential cracks (Van Zyl and Malde, 2017), it was considered to be unlikely for the example pipe, particularly since the slopes were so steep. The most likely leak was considered to be at the bottom of the pipe where the very small slope of the line is representative of leaks on steel pipes. The linear data fit for the bottom point in Figure 5 predicts an initial leak area (area under zero pressure conditions) of 13.1 mm (assuming a discharge coefficient of 0.65). Subsequently the pipe operators found three small corrosion holes on the steel section at the bottom of the pipe, confirming the prediction of the pipe test.

The results of all twelve tests are summarised in Table 1. Three of the tests could not be completed – one (I) because it was not possible to fill the pipe and two (G and H) because the isolation valves did not seal. Identifying non-sealing isolation valves is, however, valuable information for directing future maintenance work.

For the nine successful tests, three pipes were found to have large leakage with initial leakage areas greater than 25 mm^2: two of these pipes (A and C) are likely to have corrosion holes and the third (F) a significant longitudinal crack. Two pipes (B and K) were found to have significant leakage and three (D1, D2 and E) very small or insignificant leakage. The final pipe (L) was found to have a negative initial area, which is likely due to a seal only starting to leak at some positive pressure value.

Table 1: Summary of field test results

Pipe	Most Likely Leakage Characteristics		
	A_0 (mm^2)	m (mm^2/m)	Comments
Pipe A	28.4 +	0 - 0.36	Corrosion holes between Nodes 2 and 4
Pipe B	2.3	0.27	Corrosion holes at Node 2
Pipe C	33.5	0	Round holes at Node 3 (lowest node)
Pipe D1	~ 0	~ 0	Insignificant leakage
Pipes D1&2	~ 0	~ 0	Insignificant leakage
Pipe E	Very small	~ 0	Very small leaks
Pipe F	188.9	9.908	Significant crack in pipework (on strainer) at Node 1
Pipe G	-	-	Isolation valves not sealing
Pipe H	-	-	Isolation valve not sealing
Pipe I	-	-	Pipe could not be filled
Pipe K	13.1	0.005	Small corrosion holes in steel pipe at lower section (Node 3)
Pipe L	-106.8	11.48	Seal failure

5 CONCLUSION

This study conducted a number of leakage tests on pipelines in South Africa, showing that pressure-based leakage characterisation is an effective and practical method for field application. The method was able to identify pipes with leaks, estimate the leak size, type and location, and identify problems such as non-sealing isolation valves.

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