Drink. Water Eng. Sci. Discuss., 5, 403–419, 2012
www.drink-water-eng-sci-discuss.net/5/403/2012/
doi:10.5194/dwesd-5-403-2012

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Drinking Water Engineering and Science Discussions

Leakages and pressure relations: an experimental research

F. De Paola and M. Giugni

Department of Hydraulic, Geotechnical and Environmental Engineering, University of Naples "Federico II", Italy

Received: 2 July 2012 – Accepted: 9 July 2012 – Published: 25 July 2012

Correspondence to: F. De Paola (depaola@unina.it)

Published by Copernicus Publications on behalf of the Delft University of Technology.

Abstract

Leaks in water systems are presently a frequent and increasing event that involves cost increase and poor service, not compliant to quality standards and modern management criteria. The most recent data available in Italy, resumed into the report issued by Control Committee for Water Resources Use (CONVIRI), shows leakages with an average value of 37 %. It is important, for maintenance perspective, to investigate occurrence and evolution of water leaks and the analytical links between leaks Q_p and network pressure P, for a reliable calibration of water networks quali-quantitative simulation models. The present work reports the results of an experimental campaign started at Laboratory of Hydraulic of Department of Hydraulic, Geotechnical and Environmental Engineering of University of Naples Federico II in order to analyze the features of Q_p (P) relation, which are compared with principal results issued in literature.

1 Introduction

Leaks in water systems are presently a frequent and increasing event causing cost increase and poor service levels not compliant to quality standards and modern management criteria. The most recent data available in Italy are resumed into the report issued by Control Committee for Water Resources Use (CONVIRI, 2010) which shows leakages between 21 % and 61 %, with an average value around 37 %. The recovery of part of these lost water volumes would allow to acquire "new" resources and also economical benefits due to adduction, treatment and distribution cost savings. Losses reduction could obviously be achieved by well planned maintenance campaigns, both ordinary and extraordinary: they are, however, expensive actions from a financial perspective and are often not rewarded by the economical value of the recovered resource.

A different approach is to control network operation pressure by installing PRV (Pressure Reducing Valves) or realizing District Meter Areas (DMAs). For this purpose it is important to analyze the forming and evolution mechanisms of water leaks and the

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analytical links between the leaks Q_p and the network pressure P. An experimental investigation on these topics has been started at the Hydraulic Laboratory of Department of Hydraulic, Geotechnical and Environmental Engineering of University of Naples "Federico II" (De Paola et al., 2010; De Paola and Giugni, 2010), whose first results have been compared to the most interesting ones present in literature (Sendil and Dhowalia, 1992; Lambert, 2000; Thornton and Lambert, 2005; Greyvenstein and Van Zyl, 2006; Milano, 2006; Coetzer et al., 2006; Ferrante et al., 2010). The present work provides further elements related to long lasting tests.

2 Experimental set-up

Experimental tests were carried out on the Hydraulic Laboratory high pressure circulation plant. The water discharge, detected by an electromagnetic flow meter, is led to a system of two parallel air vessels which allow to keep a constant pressure up to 10 bars, and from this to a cylindrical steel adductor (800 mm diameter) connected to the test plumbing (Fig. 1). This latter in the first experimental tests was a steel pipe 100 mm nominal diameter (DN 100) and thickness $s = 4$ mm, 6.70 m long and flat; in the second experimental tests was a last generation ductile iron pipe (BLUTOP – PAM Saint Gobain) nominal diameter (DN 125) and thickness $s = 3$ mm.

At the downstream end of the experimental duct was fitted a rubber wedge sluice valve (Fig. 1), connected to a PVC ϕ110 which collects discharge to a recirculation tank. At 3.35 m downstream of the experimental pipe was installed a junction with an interception spherical valve at the end of which there is a nozzle used to simulate the occurrence of a leak (detail of Fig. 1).

During the tests the water discharge flowing out of the nozzle is collected into a tank suitably calibrated, measuring filling time or, as alternative (for the ductile iron pipe), is measured by a small size electromagnetic flow meter (DN 25) (Fig. 1). Pressure measure is run by a WIKA transducer with a 0–10 bar range and sample frequency equals to 10 Hz. For each test signals were acquired for a minimum of 60 s, calculating pressure average value.

In the tests the following parameters were varied:

1. feeding pressure, between 2 (min) and 7 (max) bars;
2. water discharge between 3 and 45 $\mathrm{l\,s^{-1}}$;
3. nozzle geometry: in particular the presence of leaks with different shape and size was simulated by using suitable nozzles: round, rectangular, square, irregular (Fig. 2);

aiming to achieve, by tests analysis, the water discharge and feeding pressure relationship.

3 Experimental results

Experimental tests were run with an approach both *static* and *dynamic*, in order to simulate various operating conditions of a water system. The static tests simulate the night operating conditions (suitable to verify more precisely leaks occurrence), while the dynamic tests simulate day running.

During each test, as mentioned before, pressure was detected at least for 60 s, in order to evaluate pressure variation features due to the leak.

3.1 Steel pipe

3.1.1 Static tests

From theoretical perspective, the relation between water leaks (Q_P) and pressure (P) is as follows:

$$Q_P = a \cdot P^b \quad (1)$$

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The experimental tests allowed to calculate for the tested nozzle shapes, with a very high correlation rate (R^2 always above 0.99), the values of coefficient (*a*) and exponent (*b*) in Eq. (1), as reported in Fig. 3. The coefficient (*a*) increases, in both cases, as obvious, according to nozzle size; the (*b*) exponent, instead, is always little far from the theoretical value 0.50.

3.1.2 Dynamic tests

Dynamic tests analyze, as already mentioned, the daily demand variation, by generating different discharge values (varying from about 3 to 45 $\mathrm{l\,s^{-1}}$ by means of downstream rubber wedge sluice valve) detected by an electromagnetic flow meter (Fig. 1). The tests duration, strictly linked to the filling time of the volumetric tank, was always about several minutes.

In these tests, leaks increase, as expected, as pressure and nozzle size increase. The (*b*) exponent tends to a constant value, close but not equal to the theoretical value 0.50, also at dynamic test conditions (Fig. 4).

It can be also highlighted that coefficient (*a*) has an almost linear trend as surface ratio A_n/A_p varies for nozzles having either square or rectangular section, while for round section it shows a parabolic trend according to d/D ratio (d = nozzle diameter; D = pipe diameter) (Fig. 4) as shown for the static tests.

3.2 Ductile iron pipe

Experimental tests for ductile iron pipes were run in the same described way but with longer duration (almost 1 h), in order to analyze leaks variations as discharge and pressure vary in the feeding pipe.

Figure 5 shows the close correlation between outflow discharge and pipe pressure for a round (6 mm diameter) and a rectangular (10 × 2 mm) nozzle. In Fig. 6 is also shown the time progress of flow experimental values compared to the points given by Eq. (1) after calibrating (*a*) and (*b*) coefficients using a genetic algorithm (GANetXL

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software, CWS, 2010). The model resulted very effective in the calculation of losses, and calibration leads to exponent (*b*) values slightly lower than the theoretical value 0.50.

The results of the dynamic tests performed on ductile iron pipe have confirmed the findings of the tests carried out on steel pipe, highlighting a growing parabolic trend of the (*a*) coefficient for the round nozzle, while slightly linear for rectangular ones. For the (*b*) exponent, tests indicate a substantial invariance, with values almost always slightly below 0.50.

4 Conclusive remarks

Starting from the first experiences run in UK (Goodwin, 1980), the relation between water leaks and pressure ratio was analyzed through the monomial Eq. (1). Some research works afterwards developed in Saudi Arabia (Sendil and Dhowalia, 1992), UK (Burnell and Race, 2000) and Iran (Ardakanian and Ghazali, 2003) by the analysis of field data on different kind of pipes and different discharge range, confirmed such equation: available data are summarized in Table 1, showing that exponent (*b*) resulted systematically higher than 0.50.

The experiences run so far in Naples for metal pipes, with pressure varying within a wide range not investigated in other experimental works, have shown as follows:

- the relation (1) allows a reliable forecast of leaks once given pressure, if (*a*) and (*b*) coefficients are suitably defined;
- (*b*) exponent resulted little far from the theoretical value 0.50 for both round and rectangular nozzles;
- (*b*) values resulted slightly dependent from test characteristics (static or long-term dynamic).

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Experimental data collected in Naples so far, therefore, confirm the results achieved by other tests for steel pipes with round nozzles (Coetzer et al., 2006), with reference to a range of pressures slightly smaller.

The (*b*) values significantly higher than 0.50 reported in literature are related instead to steel pipes affected by corrosion and asbestos cement or plastic pipes with longitudinal cracks. Probably they are due to a reduced consistence of material around the holes (due to corrosion) (Greyvenstein and Van Zyl, 2006) or to the remarkable flexibility of plastic pipes (Farley and Trow, 2003; Walski et al., 2006; Ferrante et al. 2010; Bovolin and Picciotti 2008).

For pipes characterized by high elasticity, then it would be appropriate to refer to an equation that takes into account the pressure/area link of the hole (such as FAVAD equation, Cassa et al., 2010). The analysis is made, however, further complicated by the viscoelastic characteristics of materials such as HDPE.

Further systematic experiences are in progress at the Hydraulic Laboratory of Naples on pipes of different material (HDPE, GRP), in order to acquire new elements aimed, in particular, to clarify the influence of the characteristics of the pipe and the features of the hole simulating the leak on the outflow mechanisms and, therefore, on the leakage law.

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Table 1. Exponent (b) values as reported in literature.

Source	b	Installation type
UK (Goodwin, 1980)	1.18 (average)	Operating districts with little night metered consumptions
Saudi Arabia (Sendil and Dhowalia, 1992)	0.54–1.61	Ten operating districts in Riyadh
ThamesWater (Burnell and Race, 2000)	1.00	Supply-pipe leakage patterns in over 2000 accurately-logged domestic sites
Iran (Ardakanian and Ghazali, 2003)	1.10–1.18	Old cast iron with high leakage in Sanadaj (Kurdistan)

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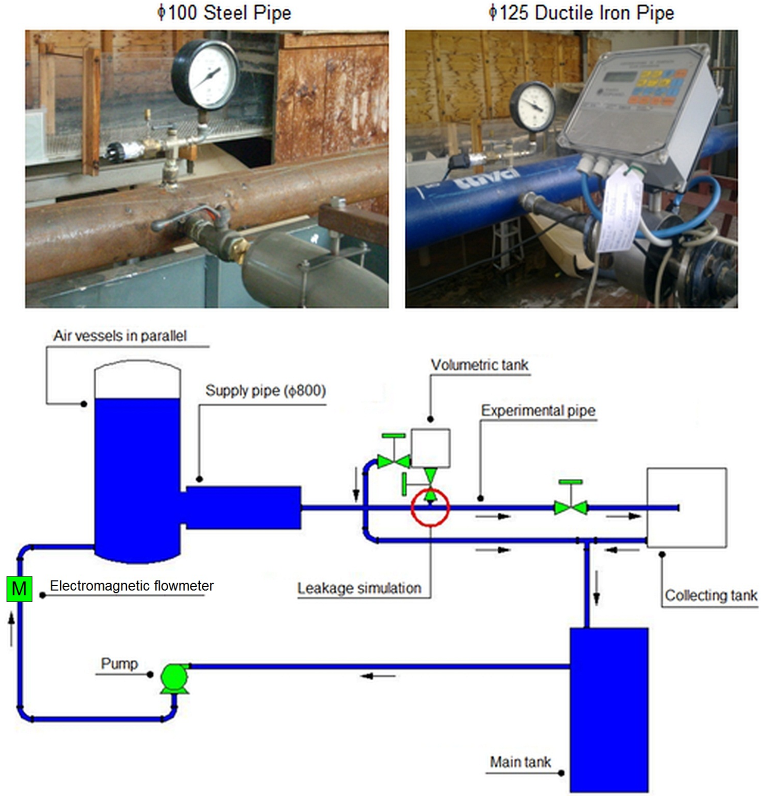

Fig. 1. Experimental installation layout.

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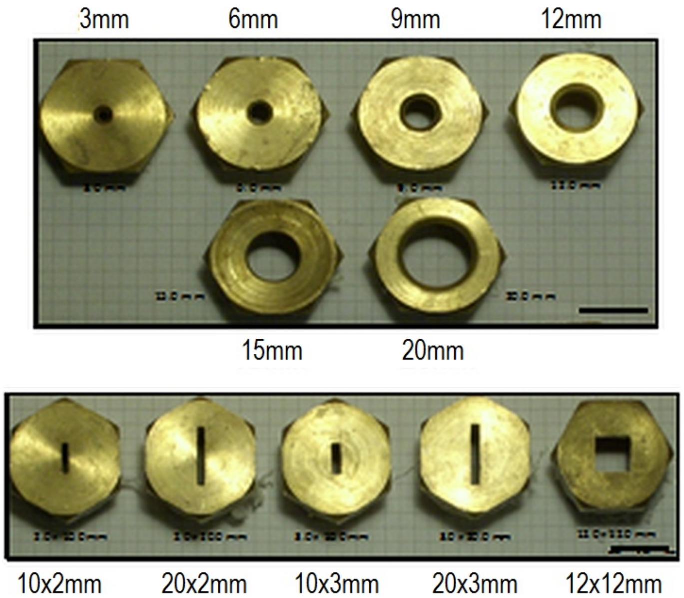

Fig. 2. Test nozzles with different shape and size.

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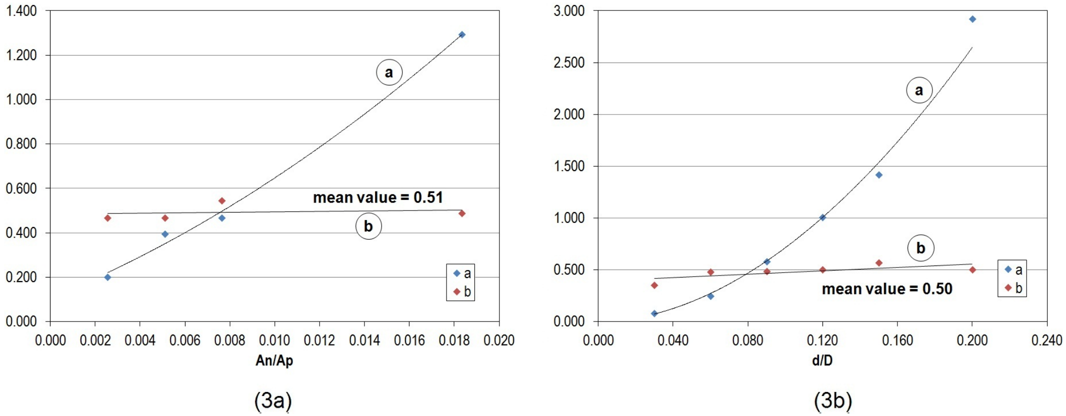

Fig. 3. Discharge coefficients according to: **(a)** surface ratio A_n/A_p (rectangular nozzles); **(b)** diameter ratio d/D ($d_{\text{nozzle}}/D_{\text{pipe}}$, for round nozzles). Static tests on steel pipe.

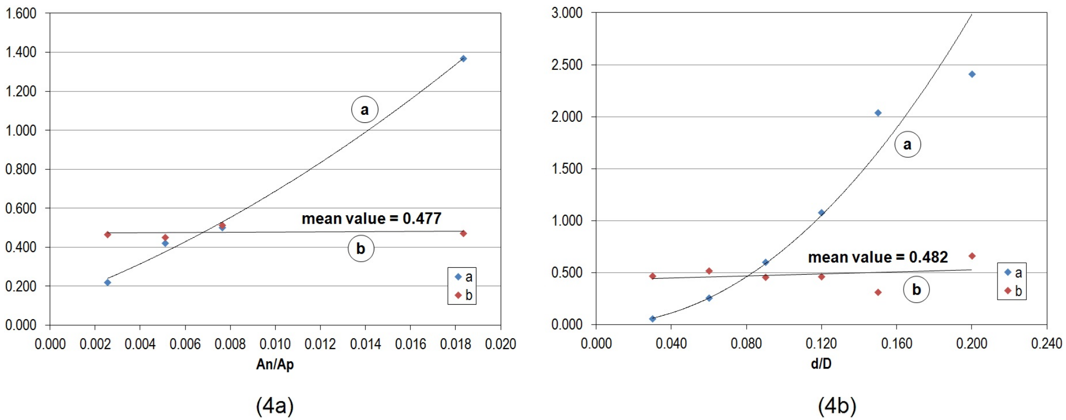

Fig. 4. Discharge coefficients according to: **(a)** surface A_n/A_p (rectangular nozzles); **(b)** round nozzles. Dynamic tests on steel pipe.

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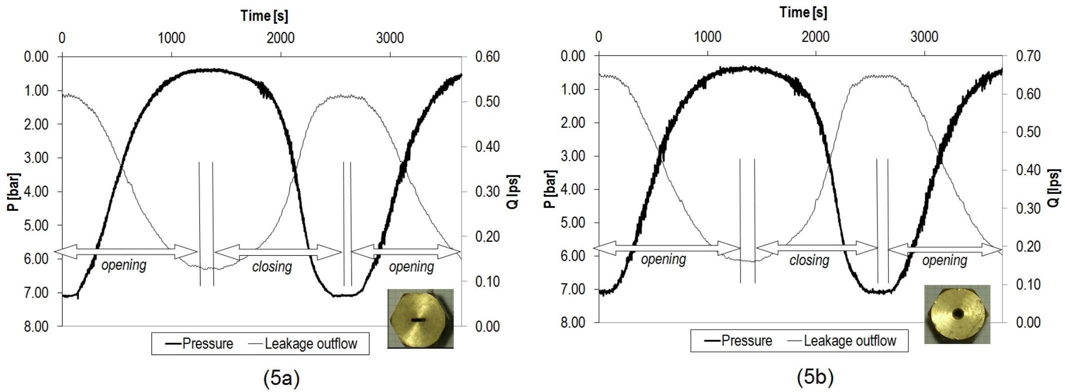

Fig. 5. Trend of detected pressures and outflow discharge for a rectangular **(a)** and a round **(b)** nozzle.

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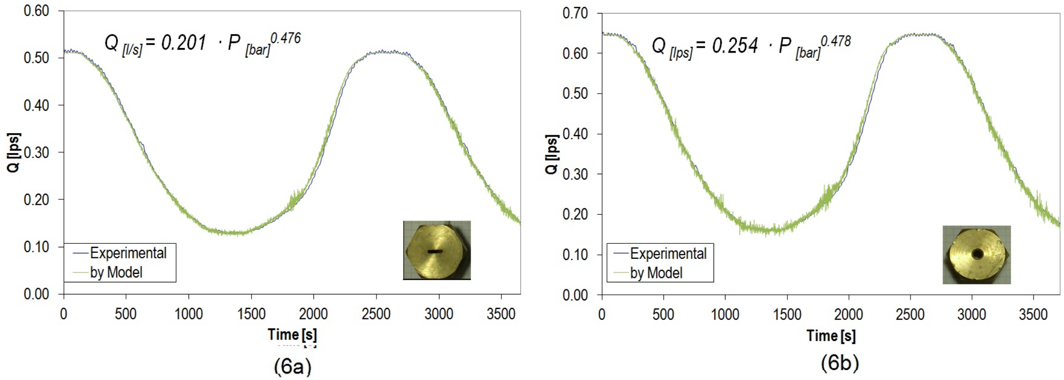

Fig. 6. Comparison between time series for measured outflows and model results after calibration (rectangular nozzles, **(a)** – round nozzle, **b**).

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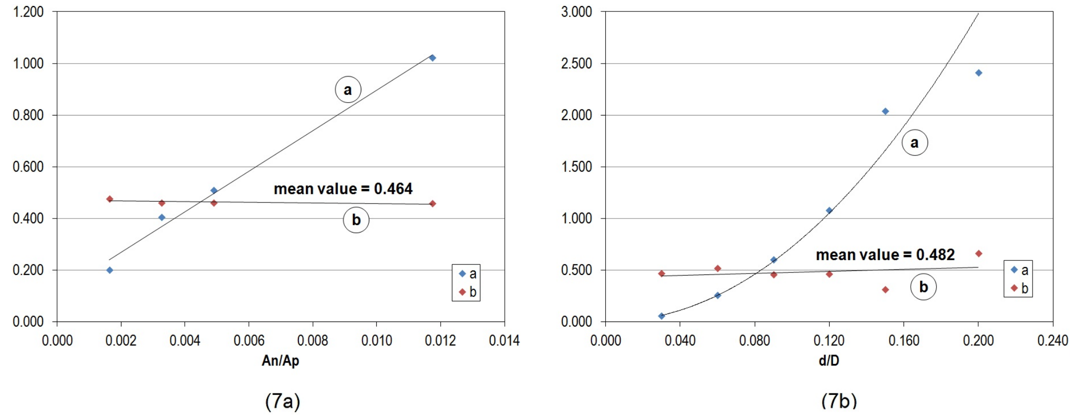

Fig. 7. Discharge coefficients according to: **(a)** rectangular nozzles; **(b)** round nozzles. Dynamic tests on ductile iron pipe.

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