Master Thesis in Hydraulic Engineering
Department of Civil, Architectural and Environmental Engineering
University of Naples Federico II
17 July 2019

Experimental and Numerical Assessment of Water Losses in a PVC-A pipe

Tutor
Prof. Eng. Maurizio Giugni

MS Candidate
Roberta Ferraiuolo mtr. M67/390

Co-Tutors
Prof. Eng. Francesco De Paola
Eng. Francesco Pugliese
Eng. Diana Fiorillo

KAY ASPECTS

- **The water losses represent a non-negligible rate for the aqueduct systems**
- **The relation between pressure-and leakage flow-rate for the PVC-A pipeline is investigated**
- **Experimental results are combinate with Computational Fluid Dynamics (CFD) simulations**

1. ABSTRACT

The assessment of water leaks in water supply and distribution systems is a topic of increasing interest for an effective sustainable management of water resources, responding to modern criteria of efficiency, effectiveness and economy.
The total drinking water volumes taken in Italy are around 9.50 billion cubic meters / year (Istat, 2019), corresponding to a daily per capita volume of 428 liter/inhabitant/day.
However, on average, about half of these (47.9%) does not reach end users due to dispersion into the water systems, producing ineffective service levels, with consequent significant operational, social and economic damages.
It is therefore necessary that the operators of the Integrated Water Service (SII) invest not only in measures aimed at identifying the management and control of losses, but also applying innovative methods to reduce them, such as active control of the pressures on the network by means of destructuralisation and pressure regulation, using Pressure Reducing Valves (PRVs).
The awareness that the efficiency of water saving starts from the in-depth analysis of the relationship between dispersed flow and pressures, directs this work to report the preliminary results deriving from both an experimental and a numerical investigation on the behaviour of PVC-A pipes, subject to physical losses due to breakage.
PVC-A is a plastic material of recent production, deriving from a mixture that combines the stability of PVC-u, with the plasticity of Polyethylene Chloride, allowing the achievement of Nominal Pressure PN up to 16 bars, therefore being suitable for aqueduct uses.
An experimental campaign was therefore undertaken at the Hydraulic Laboratory of the Department of Civil, Architectural and Environmental Engineering (DICEA) of the University of Naples Federico II, aimed at characterizing the correlation between pressure and leaked flow deriving from the formation of orifices, when operating conditions persist. The achieved results

allowed the calibration of a numerical CFD model (Computational Fluid Dynamics), starting from which the leakage law is investigated, with variations in geometry, dimensions and orientation of the orifice.
In this work the first results of the activity in progress are reported, with the intention of providing support to the knowledge related to the characterization of the behaviour of PVC-A pipes and to the consequent performance response.

2. EXPERIMENTAL AND NUMERICAL ANALYSES OF LEAKAGES LAW EQUATIONS INA PVC-A PIPLINE

2.1 Experimental Set-Up

The experimental set-up installed at the Hydraulic Laboratory of the Department of Civil, Architectural and Environmental Engineering (DICEA) of the University of Naples Federico II consists of a hydraulic circuit (Fig. 1a) which, by means of a recirculation pump, feeds an air box, operating as a compensation tank and able to define a constant pressure to the system, working in the range 1-7 bar (De Paola et al., 2014). A DN800 cylindrical feeder is connected to the tank, downstream of which is fitted with a rubberized wedge gate and a DN125 steel connection piece which conveys the water to the investigated PVC-a pipe (Fig. 1b) (PN10, DN140, length equal to 3.20 m and thickness 3.9 mm). According to the tested configuration, the orifice has a rectangular shape, of dimensions 20 mm and 3 mm, located in the center line of the pipeline, through a direction transversal to the flow.
Pressure transducers and electromagnetic flow meters placed upstream and downstream of the pipe, through an acquisition system, allow the in-continuous recording (with acquisition frequency 0.50 s) of the flowing rate. Downstream of the system a motorized needle valve is also deployed, which allows the flow regulation, simulating the static behaviour (for a fixed opening degree of the valve) or dynamic (to simulate of a variable consumption pattern).

(a) (b)

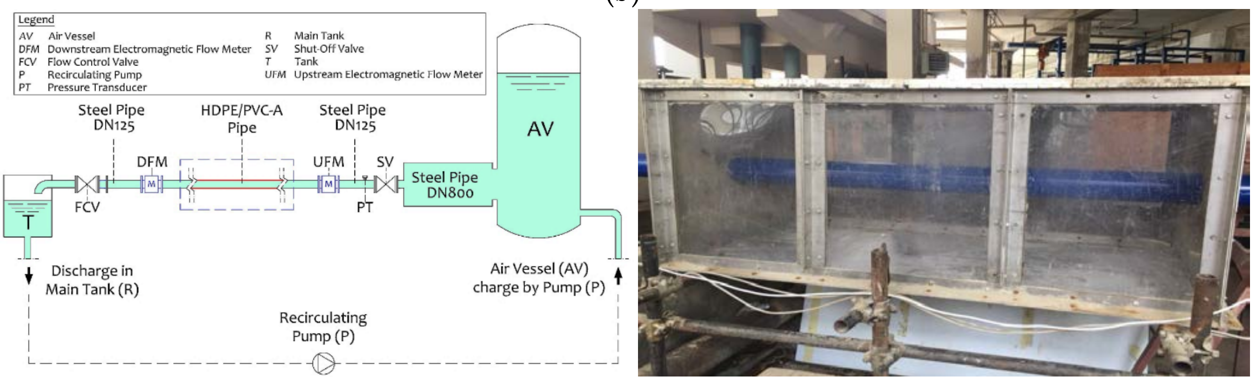


Figure 1: (a) Hydraulic sketch of the experimental set-up; (b) Picture of tested pipe

The flow rate lost through the orifice was thus estimated as the difference between the upstream and downstream flow recorded by the electromagnetic flow meters, correlating it to the acting pressure derived from the pressure transducer. The Leakage Law formula (Thornton, 2005) was applied, reproducing the efflux from a large wall orifice:

$$Q_p = \alpha P^{\beta} \tag{1}$$

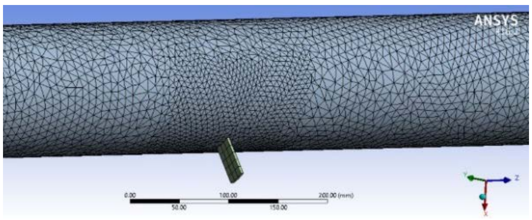
with $\alpha = \sigma\mu\sqrt{2g}$ e $\beta = 0.50$.

being σ the cross-section of the orifice, μ the efflux coefficient and g the acceleration of gravity. From the tested PVC-a material, it was observed how these the Leakage Law coefficients do not significantly differ from the theoretical values. Indeed, with reference to 41 static tests lasting about 300 s (for a fixed degree of opening of the needle valve, simulating the night-time behaviour of a water distribution network) performed in a pressure range from P 1 to 7 bar and flow rates Q of 10, 20 and 30 l/s, the parameter $\alpha = 0.524$ and the exponent $\beta = 0.498$ were calibrated, respectively.

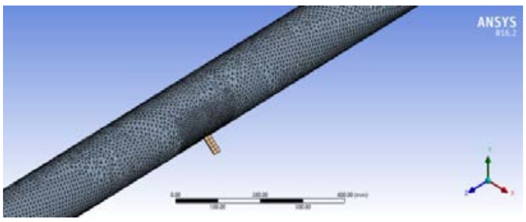
2.2 CFD Numerical Simulations (Computational Fluid Dynamics)

Starting from the experimental results, a 3D model was implemented in Ansys (2016) platform, to numerically reproduce the flow behaviour of the outflow efflux.
The first step provided the design of the geometric pipe model; then the internal fluid domain was extracted, adding an extended rectangular element having length equal to 5 times the equivalent diameter of the orifice. The latter was useful to correctly set the boundary condition at the leak. The mesh generation required a sensitivity analysis, aimed at defining the resolution of the optimal mesh, intended as the right balance between the experimental-numerical relative scatters (estimated in terms of the flow velocity at the loss, admitting a maximum error of 11.4%) and allowable computational efforts. The adopted mesh (of about 9 million elements and 10 mm sizing) consists of tetrahedral-shaped cells, for both the pipe and the fluid domain, with fitted resolution at the orifice (sizing 5 mm), useful to improve the accuracy of the solution around the leak point. The efflux in the atmosphere was set as a boundary condition at the loss, whereas the mass flow rate and the pressure were set at inlet and the pressure was set at outlet. The Realizable k-ε turbulence model was applied, with SIMPLE solving operator, with a second order accuracy.
Once the model was calibrated with the transversal orifice, different geometric orifices were simulated, namely both a longitudinal rectangular (Fig. 2b) and a circular orifice (Fig. 2c), having the same area of the experimentally tested one equal to about $6.0 \cdot 10^{-5}$ m². A longitudinal crack (Fig. 2d) was also simulated with length of 20 cm.

(a)



(b)



(c)

(d)

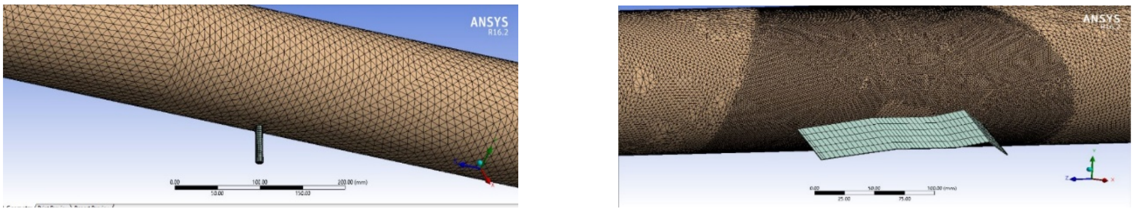


Figure 2 (a) Transversal rectangular orifice; (b) Longitudinal rectangular orifice; (c) Circular orifice; (d) Crack

With reference to the transversal rectangular orifice, both the experiments and the numerical simulation provided the Leakage Law effectiveness to reproduce the efflux phenomena with Leak Exponent close to the theoretical value of 0.50. Moreover, no visco-elastic effects were observed to the short time span of the tests, in the order of 300 s. Results from both longitudinal and circular orifice were comparable to the transversal ones, whereas the crack provided higher flowing rates due to the greater leak area.
The modeling is going to be improved by simulating both the dynamic daily pattern of a water distribution network and the interaction between the leaked pipe and the surrounding soil.

REFERENCES

- ANSYS, 2016. ANSYS Fluent User's Guide. Sito web: http://148.204.81.206/Ansys/150/ANSYS%20Fluent%20Users%20Guide.pdf
- De Paola F., Galdiero E., Giugni M., Papa R., Urciuoli G., 2014. Experimental Investigation on a Buried Leaking Pipe. *Procedia Engineering*, 89, 298-303
- FITT BluForce Catalogo, 2018. Sito web: https://bluforce.fitt.com/#catalogo
- Istituto Italiano di Statistica ISTAT, 2015. Censimento delle acque per uso civile. Anno 2012. Statistiche Report ISTAT. Sito web: http://www.istat.it/it/files/2014/06/2014_06_26_Report_censimento_acqua.pdf?title=Censimento+delle+ac-
- Thornton J., Lambert A., 2005. Progress in practical prediction of pressure: Leakage, pressure, burst frequency and pressure. *Proceedings of IWA Special Conference Leakage 2005*, International Water Association, London