Air valves dynamic behaviour

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Abstract

Many pipe bursts in water distribution systems are caused by entrapped air. Air valves are the devices responsible for releasing and admitting air into the pipe. However, the dynamic behaviour of these elements is not very well known and the number of references on this topic is limited and scarce. Comprehensive air admission and release tests for determining the dynamic behaviour of air valves were carried out at WL| Delft hydraulics laboratory for DN50 and DN100 air valves, mounted on a 200mm and 500mm pipe respectively. In this paper, a brief description of the experimental set up and test procedures is provided. Some conclusions about the importance of different parameters on the peak pressure magnitude, such as terminal water velocity, residual air volume, moving water column inertia, are also presented.

Keywords: Air valve, entrapped air, water hammer,.

Introduction

Entrapped air problem is a well known phenomenon that may cause numerous problems in all types of systems, independently of their elevation profile. It appears not only during the filling or draining of the pipes but also during the normal operation of the network. Even though a pipe is completely full of water, dissolved air may come out at high points due to low pressure conditions. Air may also come in from a reservoir or a pumping station, due to the appearance of vortices at the intake.

Air pockets usually cause high pressure peaks that can produce a burst in the pipe (Fuertes, 2001). Furthermore, entrapped air reduces the transportation capacity of the pipe generating additional head losses. Moreover, during the drainage of the system it is essential to admit some air in the pipe to prevent underpressures that will produce the collapse of the pipe.

Air valves are used to ensure the release of the entrapped air accumulated during the normal operation of the system and the filling of pipes. They are also installed to admit air into the system during its drainage, preventing the appearance of sub-atmospheric pressures.

Knowledge of air valves performance under different conditions is essential to reduce the risk associated to pressure transients. Nevertheless, manufacturers only provide users with the static discharge capacity of the valves at best, neglecting the effect that

dynamic conditions may have on this parameter. For this reason, it is not possible to know the effect of air valves in the transients produced by other elements in the system.
It is also possible that an excessive discharge capacity of the air valve causes high pressure peaks when water closes the valve (Campbell 1983, Vent-o-Mat, 1995, Blum, 1994, Stephenson 1997, Fuertes, 2001). In these cases, the water hammer its initiated at the air valve. To accurately determine the flow deceleration produced by the air valve float movement and therefore the pressure peaks generated, its dynamic behaviour must be known. In fact, some references (Stephenson 1997, Vent-o-mat 1995) propose methods to reduce flow deceleration in the final stages of the air release, by slowing down the closure of the air valve.

To date, the study of transients in which air valves are involved only consider their static characteristics. The existing software for dynamic analysis of pressurise systems seldom take into account air valves, and when they are considered the only parameter used to simulate their behaviour is the static discharge capacity. Besides it is always assumed an instantaneous closure or opening of the valve and only few models (Wanda, WL Delft Hydraulics) allow to define a residual air volume near the air valve after its closure.

In our knowledge, there is hardly any study dealing with dynamic behaviour of air valves. Blum (1994) describes the tests conducted by the U.S. Bureau of Reclamation on several types of air valves with different water filling velocities. In this work only the pressure peak measured in each event was reported. A similar test was carried out by the Council for Scientific and Industrial Research in South Africa for a DN80 air valve discharging at a differential pressure of 0.17 bar. In this test, reported in Vent-o-Mat (1995), a peak pressure of 140 bar was measured.

Nevertheless, more research has been carried out for other elements, like for example check valves, for which dynamic behaviour has been extensively studied (Kruisbrink et al. 1994, Kruisbrink, 1996).

With no doubt, the availability of adequate facilities to carry out the experiments at full scale level, the complexity of the physical phenomenon and the existence of a two-phase flow has been the cause of the scarce research on this topic.

During 2002 a project entitled “Dynamic behaviour of air valves” has been carried out at WL| Delft Hydraulics laboratory in the frame of the Transnational Access to Major Research Infrastructure Program financed by the European Union. This laboratory has the adequate facilities to test air valves dynamic behaviour at real scale as well as an extensive experience in hydraulic transients experiments.

The aim of the project is to study air valves dynamic behaviour during air release/admission operations in a full scale set up. Due to the theoretical complexity of the problem and the amount of data recorded in the laboratory, the data analysis has been divided into two stages. On the first part the following topics will be studied:

- Magnitude of overpressures and underpressures generated.
- Identify phenomenon sensitivity to different parameters.

On the second stage it is intended to

- Generate a numerical model that can simulate the dynamic behaviour of air valves and compare it with existing models.
- Define dimensionless parameters that characterise the dynamic behaviour of air valves so that pressure surge and water hammer can be predicted.

General description of the facility.

Tests for DN50 and DN100 air valves provided by several manufacturers were carried out in three periods during 2002. Basically three test types were conducted under different conditions:

- Static characterisation of air valves.
- Air release dynamic tests.
- Air admission dynamic tests.

From those, this paper only focuses on dynamic tests, since static tests are usually provided by the manufacturers for every commercial air valve and exhibit no scientific significance.

A scheme of the dynamic test facility is presented in figure 1. The same configuration, with different pipe diameters of 500 mm and 200 mm, was used for both, DN50 and DN100 air valves. The dimensions for each test section are defined in table 1. As it can be seen the same scale factor was maintained, when possible, for every element in the facility so that this parameter could be included in a future mathematical model.

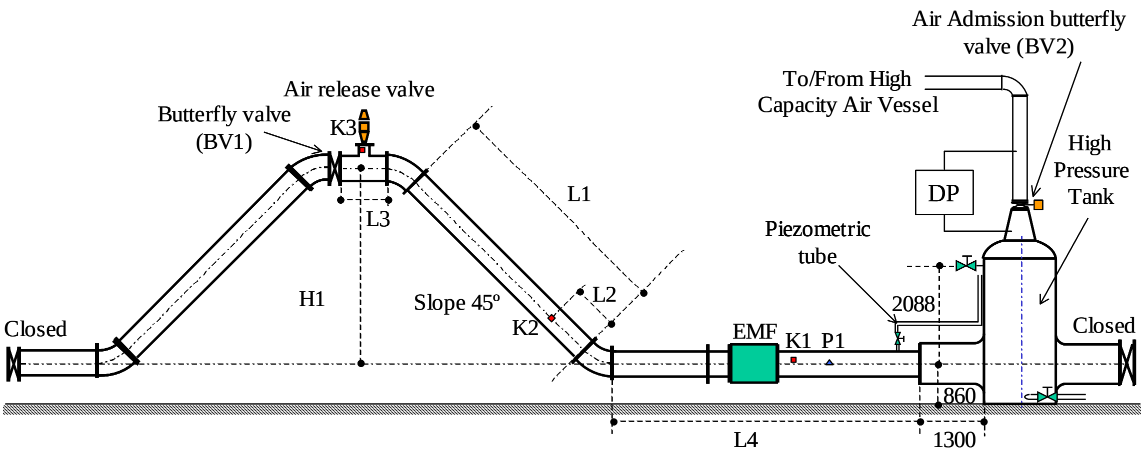

Figure 1. Dynamic test section

Table 1. Test facility dimensions.

Air Valve	DN100	DN50	Scale factor[1]
Test Pipe diameter (mm)	500	200	2.5
L1 (mm)	5000	2000	2.5
L2 (mm)	950	375	2.5
L3 (mm)	900	530	1.7
L4 (mm)	6450	2610	2.5
H1 (mm)	4109	1680	2.4

[1] Scale factor between DN100 and DN50 test sections.

Test section configurations

From the beginning of the project, closure time, moving water column inertia, residual air volume and terminal velocity (water velocity when air valve becomes fully closed) were identified as critical in the measured pressure peak. Lab tests were designed so that information about these parameters could be obtained and their effect on the pressure peak determined.

The purpose of the experiments was to determine the effect of the above parameters on the pressure peak measured at the air valve.

- Terminal velocity was adjusted modifying the initial differential pressure between the high pressure tank and the air vessel (DP).
- Dynamic tests were conducted for different moving water column inertia, filling the high pressure tank to a higher or lower water level.
- Different pipe configurations (Figures 1 and 2) were used, providing different quantities of residual entrapped air at the end of the test.
- Since two commercial air valves were used in the tests, with two types of construction characteristics, different closure profiles would be expected for each one.

The configurations used in the tests are described in table 2. For each configuration several test types - with different water inertia, differential pressure (DP) and water level in the pipe - were conducted.

Table 1. Configuration of the tests facility

Configuration	BV1	Air valve installation	Flow direction	DP[1]	Figure
1	Close	On T-Bend	Release	Positive	1
2	Open	On T-Bend	Release	Positive	1
3	Close	On short pipe [2]	Release	Positive	2
4	Close	On long pipe [2]	Release	Positive	2
5	Open	On short pipe [2]	Release	Positive	2
6	Open	On long pipe [2]	Release	Positive	2
7	Close	On T-Bend	Admission	Negative	1

[1] DP represents the initial differential pressure between the air vessel and the high pressure tank.

[2] Only on 200mm test section, for DN50 air valves.

Test procedures

For air release tests (test configurations 1 to 6), water column is put into movement pressurising the 6.6 m^3 high pressure tank. Pressurisation is almost instantaneous due to the fast response air admission valve (BV2) installed in between the high capacity air vessel and the high pressure tank. Several differential pressure values (DP) between these two tanks were used during the tests to obtain different water column accelerations. The dimensions of the air vessel ensured a constant pressure at the high pressure tank during the experiments.

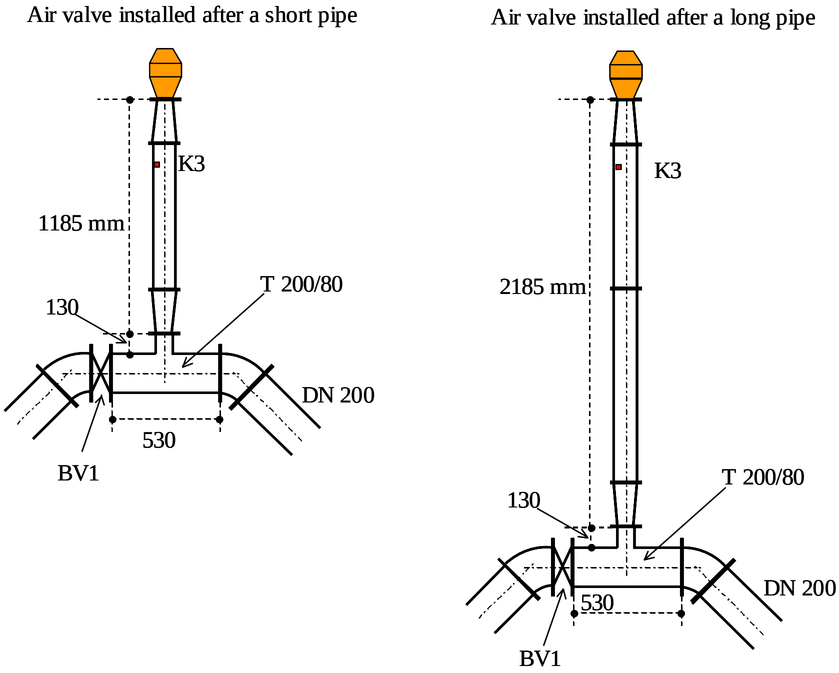

Figure 2. Configuration for test sections 3 - 5 (left) and 4 - 6 (right).

The amount of air to discharge was controlled by filling the pipe (high pressure tank) to the desired level. Since the length of the pipe is constant, this parameter is also related to the inertia of the water column.

Butterfly valve (BV1) was open for configurations 2, 5 and 6, so, in these cases, the blocking element was the water on the downstream pipe. Experiments were carried out for different lengths of the blocking water column in order to analyse the effect of this parameter in the quantity of air that remained entrapped after the first closure of the air valve.

In any air release configuration when the moving water column reaches the top of the pipe, the air valve float moves up and closes the valve producing a fast water velocity change and, consequently, an important pressure rise. Not all the air in the pipe is released and some quantity remains near the valve (residual air volume). This parameter has been identify as one of the most important in peak pressure values.

For air admission tests (configuration 7) the pipe is completely filled of water to ensure an initial closure of the air valve. To do this, first of all, it is necessary to pressurised the high pressure tank to rise the water column up to the air valve. Afterwards a negative DP is generated opening BV2. The fast movement of the water column produces negative pressures at the top of the pipe opening the air valve. The air admission through the air valve increases the internal pressure of the pipe. By setting different values of DP it is possible to control the magnitude of the event and the underpressures generated.

Instrumentation

Before starting the tests two aspects about the instrumentation were carefully considered: accuracy and frequency response. For this reason, all the instrumentation, including pressure transducers and the flow meter, was calibrated in the laboratory. The dynamic pressure transducers used (K1, K2 and K3) had a frequency response as high as 50 kHz. However, the main point of concern was the frequency response of the electromagnetic flowmeter available in the laboratory, since there is not an easy procedure for a dynamic calibration of this type of devices. This special meter was successfully used in previous studies to characterise the dynamic response of check valves. The measurements results confirmed the fast response of the instrument, so the information given in the specification sheets was accepted as valid. For example, as seen in figure 4, the maximum pressure is measured almost at the same time as the flow becomes zero, that is, when the air volume is minimum. This coincidence is only possible if the flowmeter is able to "follow" signal variations, otherwise a delay between these two variables would have been detected.

The location of pressure transducers and the electromagnetic flow meter at the pipe, is shown in figure 1. Basically, the instrumentation consists of:

- Three Kistler fast response differential pressure transducers (K1, K2 y K3).
- A high frequency response electromagnetic flow meter (EMF).
- A high accuracy absolute pressure transducer (P1).
- A temperature transducer installed at the air valve section.
- An absolute pressure transducer installed in the High Capacity Air Vessel.
- A fast response analogue displacement transducer that is fit to the air valve float and gives information about its vertical position.
- The initial water level in the high pressure tank was measured using a piezometric tube.

All the instrumentation described was connected to a data acquisition equipment that collected data every 1 ms.

Tests results

Figure 3 shows an example of the transient generated during typical air release test. As it can be seen detailed information about the float position, pressure at the air valve and water velocity is available. The float position is given as per unit, where a value of 0 indicates that the air valve is fully open and a value of 1 is obtained when the air valve is completely closed.

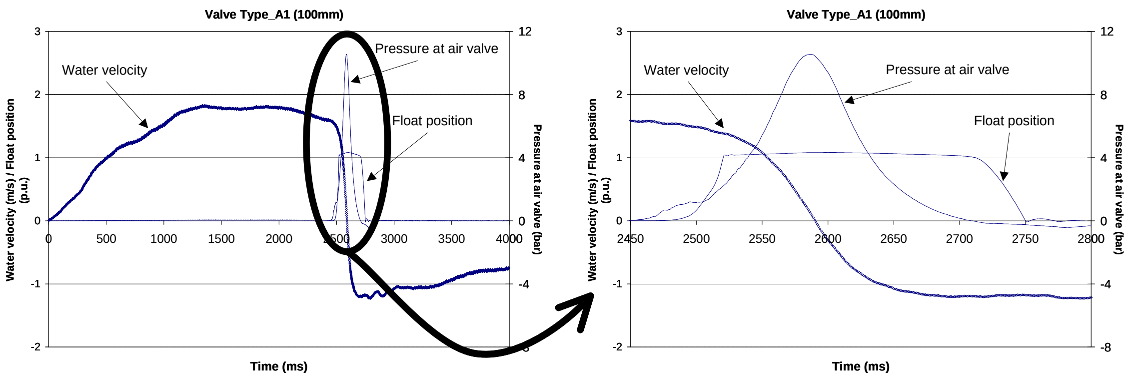

Figure 3. Transient recorded during an air release test.

One of the aims of the project was to analyse the discharge coefficient during the test under dynamic conditions. With the information recorded it is possible to calculate how this parameter changes during the transient. Figure 4 proves that the value of Cd stays constant until water reaches the air valve.

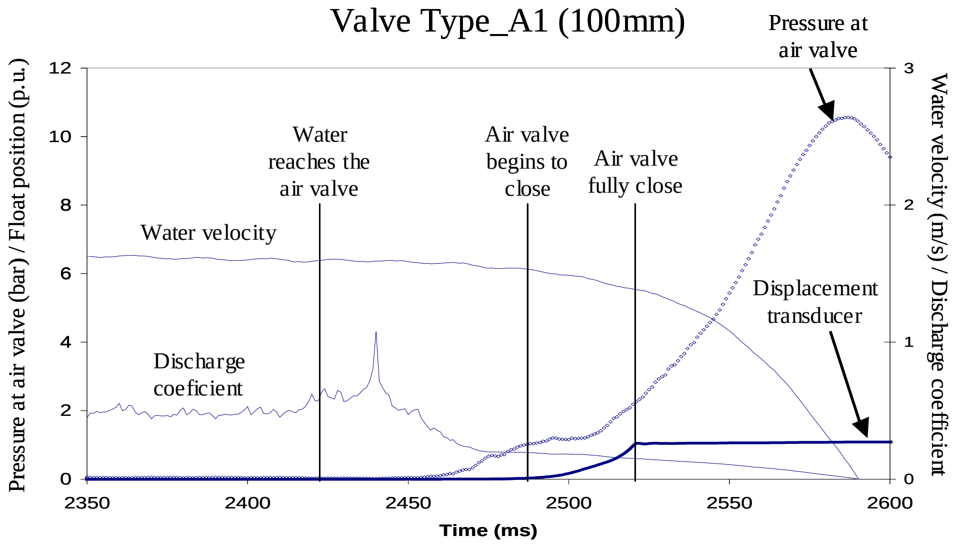

Figure 4. Final stage of an air release event.

In the following figures pressure peak is related to different parameters for DN100 air valves.

Pressure peak vs Differential pressure for two inertias

Tests showed different relations between pressure peak and DP for the two inertia considered (8.1 m^3 and 10.4 m^3). For the tests with lower water inertia (inertia 1) peak pressure values were higher for the same differential pressure than test with greater inertia (inertia 2). This is caused by the higher acceleration that a given differential pressure produces in both cases. Valve type A1 produces a slightly lower pressure peak, for the same differential pressure, than valve type B.

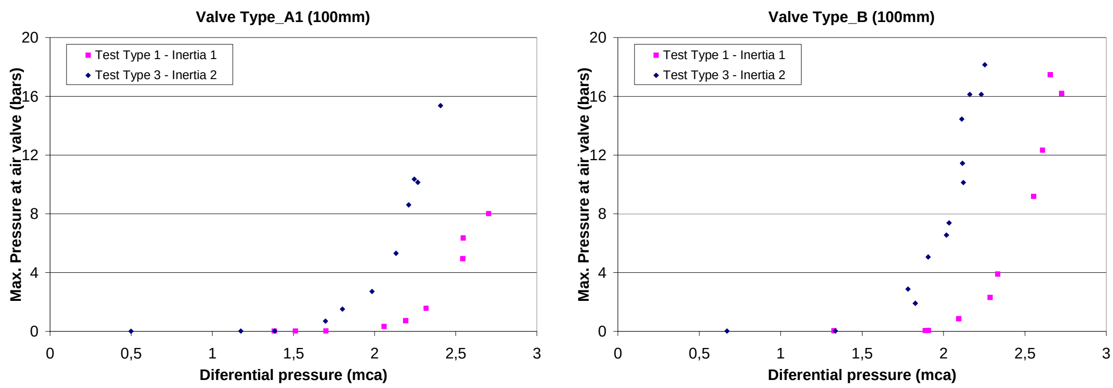

Figure 5. Pressure peak vs. Differential pressure for DN100

Pressure peak vs terminal velocity

A straight forward relation between pressure peak at the air valve and terminal velocity (water velocity when air valve completely closes) was found for both valves. For both valves pressure peak is always smaller than Joukowsky calculated using a wave celerity of 1000 m/s.

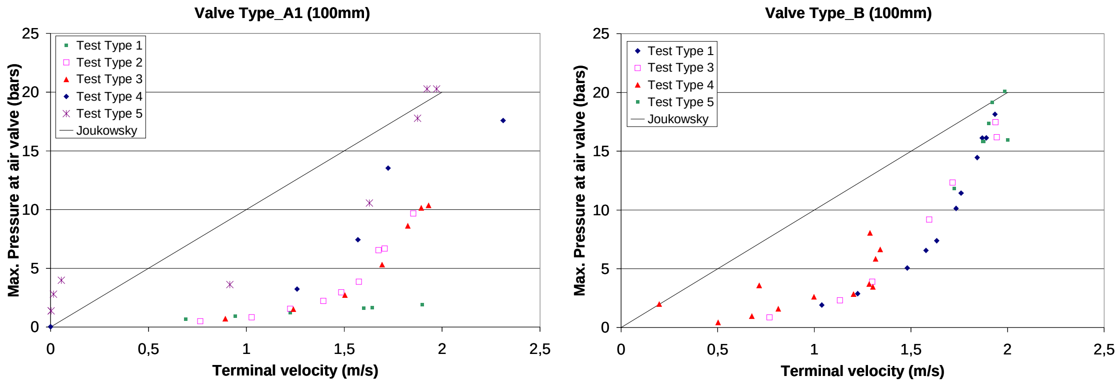

Figure 6. Pressure peak vs. Terminal velocity for DN100

Closure time vs Pressure peak

The closure time for both valves varied from 120 ms to 30 ms depending on the speed at /which the water front reaches the air valve. For slower closure times, up to 40 ms, closure time and pressure peak are strongly dependent. Closure times faster than 40 ms have almost no effect on the pressure peak. In these cases terminal velocity and residual air volume have a major effect on this parameter.

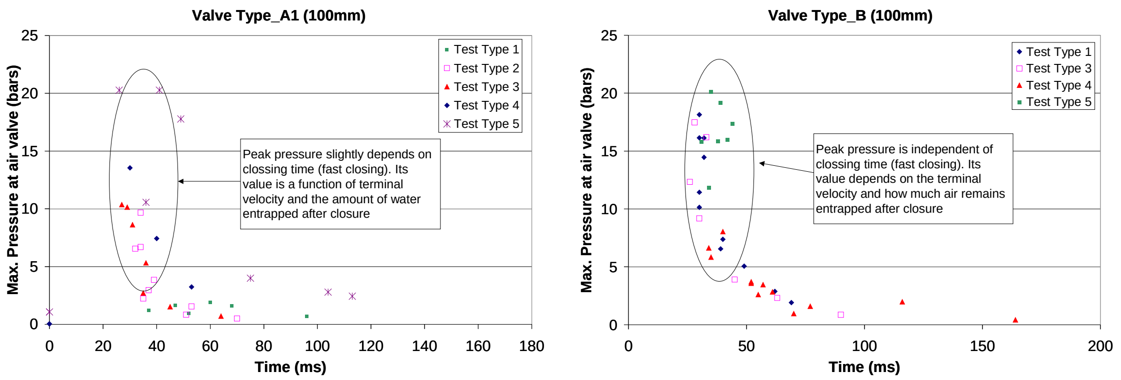

Figure 7. Pressure peak vs. Closure time for DN100

Closure time vs Terminal velocity

A strong linear relation between these two parameters was found for both 100 mm valves. However, for valve type B the dispersion from a straight line is lower than for valve A1, which once more proves the randomness of the closure time for valve A1.

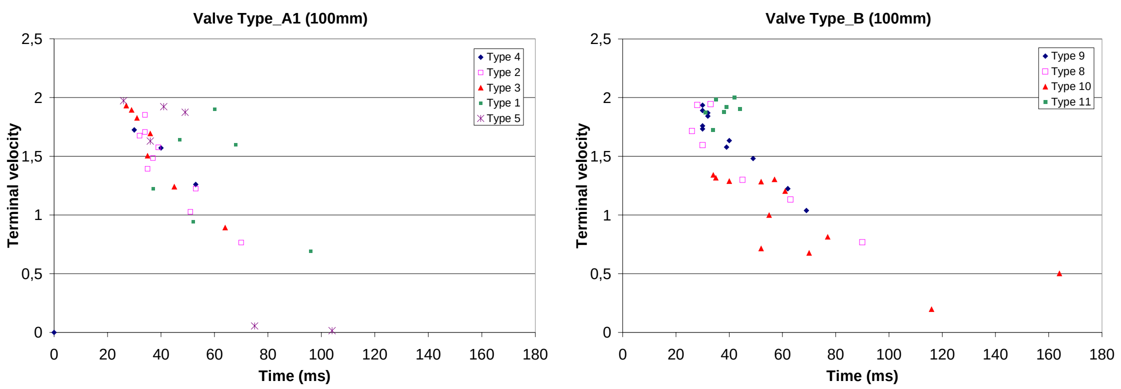

Figure 8. Terminal velocity vs. Closure time for DN100.

Conclusions

The firsts results obtained from the E.U. project entitled “Dynamic behaviour of air valves” are presented in this paper. Entrapped air volume, terminal velocity and closure time of the air valve has been identify as critical in the magnitude of the pressure peak measured. Recorded peak pressure has been always smaller than the Joukowsky peak associated to the measured terminal velocity due to the cushion effect originated by entrapped air (figure 6).

Acknowledgements

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References

Blum L.J. (1994). *Laboratory test of air valve performance.* U.S. Bureau of Reclamation. Internal report.

Cabrera E., Fuertes, V.S., García-Serra, J., Iglesias, P., Izquierdo, J. (1997). *Llenado de tuberías con aire atrapado.* Ingeniería del Agua. Vol. 4, September 1997.

Campbell, A. (1983). *The effect of air valves on surge in pipelines.* Proceedings of the 4th International Conference on Pressure Surges. Bath (England).

Fuertes, V. S. (2001) *Transitorios hidráulicos con aire atrapado.* PhD. Thesis. Polytechnical University of Valencia.

Kruisbrink, A.C.H., Thorley, A.R.D. (1994). *Dynamic characteristics for damped check valves.* Proceedings of the 2nd International Conference on Water Pipeline Systems
Edingburgh, Scotland.

Kruisbrink, A.C.H. (1996). *The dynamic behaviour of check valves in pipeline systems.*
Ph.D Thesis. City University London. Delft University Press. The Netherlands.

Stephenson, D. (1997). *Effects of air valves and pipework on water hammer pressures.* Journal of Transportation Engineering. ASCE Vol. 123, No. 2. 1997

Vent-o-Mat (1995). *Points to consider when sizing&positioning air release&vacuum break valves for water pipelines*. http://www.ventomat.com

WL Delft Hydraulics. *Wanda (Software for hydraulic design and dynamic analysis of pipeline systems).* http://www.wldelft.nl/soft/wanda/