On detecting gas pockets in pressurised wastewater mains

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Abstract
In the Netherlands, wastewater is mostly collected in combined sewer system and transported to a WWTP through pressure mains. These pressure mains form an element of the system that did not receive much attention lately with respect to monitoring of performance and maintenance. For that reason, their state of functioning is often not known. Failure of operation is only noticed when during storm conditions the capacity of the system drops, resulting in undesirable discharge to the surface water.

A recently made inventory showed that about half of the pressure mains show increased pressure loss for no obvious reason. Reduction of the systems nominal capacity can result from many causes, like increased wall roughness, scaling and the occurrence of free gas in the pipeline. The occurrence of gas-pockets may be caused by degassing of dissolved gas, but also by air entrainment at the pump inlet or at air valves.

A research project is started that will be carried out from 2003 to 2005. This project focuses on three goals:
the description of the gas-water transport phenomena in wastewater pressure mains,
a method to detect and diagnose gas problems, and
to overcome future problems by either applying remedial measures or by developing improved design methods for wastewater pressure systems.

The project is carried out by the University of Delft and Delft Hydraulics in collaboration with the majority of the water boards in the Netherlands. Two experimental facilities are constructed to investigate the phenomena, one having a length of 630 m. This paper describes the layout of the experimental set-up to detect and diagnose gas problems.

Keywords: wastewater transport mains, capacity reduction, gas-liquid mixture experiments, phenomenon description, diagnose problem pipelines.

Introduction

The hydraulic capacity of pressure mains does change during its operational life because of scaling, the occurrence of air/gas pockets, wear of pumps etc. In practical cases it is no trivial task to identify the cause of capacity loss in the first place. To find a sound solution for a 'problematic' pressure main is in many cases even more difficult since in a significant number of cases a basic design problem seems to be the cause. Free gas in pressurised pipelines/mains can significantly reduce the flow capacity. When the capacity of wastewater pressure mains fails to be in line with the design value, undesirable spills or efficiency loss may be the result.

Delft Hydraulics and Delft University started an extensive research programme in 2003 in the processes. The objectives of this programme are:

- Developing a method to quickly diagnose the cause of capacity loss of a pressure main.
- Get insight in the processes and main parameters influencing scaling.
- A quantitative understanding of the processes involved in the dynamics of air/gas pockets in pressure mains
- Obtain a better code of design practice in terms of avoiding scaling and the occurrence of persistent air/gas pockets in pressure mains.

In this paper only the first objective mentioned is addressed, discussing the set-up of the experimental facility only. The occurrence of free gas in pressure mains significantly influences system dynamics. The difference in dynamic behaviour is a measure for the amount of free gas present and is therefore used as a tool to diagnose and troubleshoot a problem wastewater main. f the presence of gas alters the wave speed, the presence of gas pockets can be proven, by sending pressure waves through the pipeline.

The objectives of the study is to diagnose a pipeline that suffers from capacity reduction. Preferably, a method is developped that diagnoses the system with simple measuring devices such as pressure transmitters only, without the need for special instrumentation.

In this paper a description is given of the experimental facility in which the influence of air and local air pockets can be investigated. An exploratory investigation has been carried out using numerical simulation of free gas pockets in pressurised mains/pipelines.

Theory and methodology

The propagation speed c (celerity) of a pressure wave through a pipeline is determined by the compressibility of the fluid and of the material of the pipe. The equation for the celerity of pressure waves for completely filled pipes with a singele fluid reads:

$$c = \left(\frac{\rho}{K} + \frac{\rho D}{eE} \right)^{-0.5}$$

in which

ρ = density of the fluid
K = Bulk modulus of the fluid
D = Inside diameter of the pipe
e = thickness of the pipe wall
E = Young's modulus

The propagation speed of pressure waves through a pipeline is significantly influenced by the amount of free gas present in the pipe. Free gas increased the compressibility of the fluid and thus reduces the wave speed.

In case free gas is (homogeneously) present ρ and K can be replaced with ρ^* and K^*.

$$\rho^* = (1-f)\rho_v + f\rho_g$$

$$\frac{1}{K^*} = \frac{1-f}{K_v} + \frac{f}{K_g}$$

The fraction f of gas in a pipe can be assessed, if the occuring wave speed and material constants are known. In order to assess the presence of free gas one could determine the change in the wave speed. The period T of the wave for a system of length L bounded by reservoirs is:

$$T = \frac{2L}{c}$$

If the period is measured for a system, the resulting (lower) celerity indicates whether free gas is present. Three different situtations can be defined:

1. The pipe is completely filled with water
2. Air is present and is distributed homogeneously over the length of the pipe
3. The pipe is filled with water and only a certain local point a volume of air is present.

For the first situation, the basic equation for wave speed is valid.
The equation for the wave speed for water with homogeneously mixed gas may not be completely valid for situation 2, since air bubbles will be intermittantly transported at the upper side of the pipe's diameter. The system of situation three can be regarded as two subsystems in between a gas pocket and the systems boundary. All three situations can be tested in the experimental set-up.

In practice, air and gas in pipelines can be devided in two main categories, local accumulation for example at high points and air that is spread over the length of the system. The experimental set-up is designed in a manner that both situations can be investigated. Local air pockets are investigated by injecting an amount of air into a vertical standpipe that is connected to the main line with a T-junction. If air that is equally distributed over the pipeline is investigated, the branch of the T-junction is closed and air is introduced in the system at the beginning of the pipeline. A description of the experimental set-up is given in the next section.

Experimental set-up

The experiments are to be conducted in a dedicated facility for research on air/gas pockets. The circuit consists of 630 m long PVC pipes with innner diameter of 235,4 mm and a wall thickness is 7,3 mm. At four locations (see arrows in Figure 1), transparent T-junctions are applied that combine the ability of visual observation and the possibility to contain a certain amount of air at a fixed point along the pipeline. The circuit is located indoors of a large facility building and is situated on the concrete floor. The pipeline is supported by steel supports at each pipe section (10 m length) and wooden blocks to prevent sagging of the pipe. The circuit is sufficiently flat to realise troublefree transport of the air bubbles. Good support is also necessary to minimise negative side effects of fluid structure interactions on the line pressure during pressure transients.

Air can be injected into the system in two different manners. If tests are required with local air pockets, air is locally trapped in vertical standpipes (branch of a T-junction) at several locations.

Figure 2 shows a layout of the standpipe used. The diameter of the standpipe is equal to the main pipe and the height is 1.00 m. At the top of the standpipe, two tappings are applied to inject and release air and to install a pressure transmitter. During experiments with local air pocket a fixed amount of air is injected in the standpipes. By reading the water level in the standpipe the exact volume is obtained at the initial line pressure at stationary flow condition.

The circuit allows investigation of the transport of air that is spread over the entire length of the pipeline. The facility is specially designed to inject a controlled and monitored airflow into the liquid phase. For these tests, air is injected at the beginning of the circuit, just downstream of the pump (upper left side of Figure 1). During these experiments the branch of the T-junction is closed.

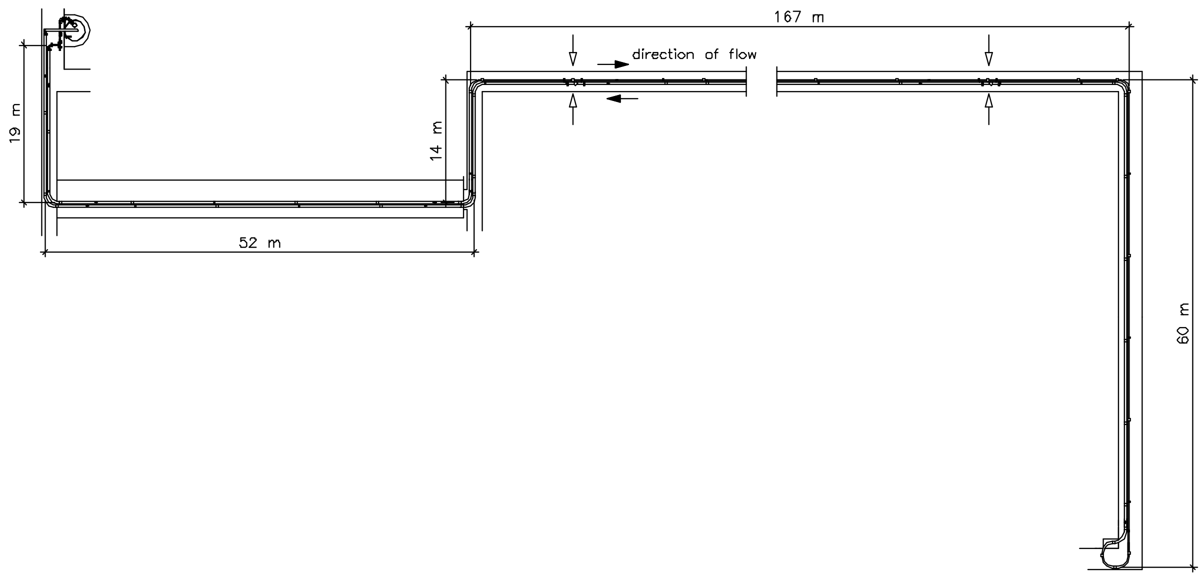

Figure 1: Top and side view of the experimental set-up.

From a constant head reservoir a pump circulates water through the experimental facility. A flow control valve (FCV) in combination with an EMF flowmeter and PC adjust the flow rate to its set value. The injection of air into the system results in a head increase of the pump, causing the flow rate to drop. The flow control allows a constant flow rate during head changes.

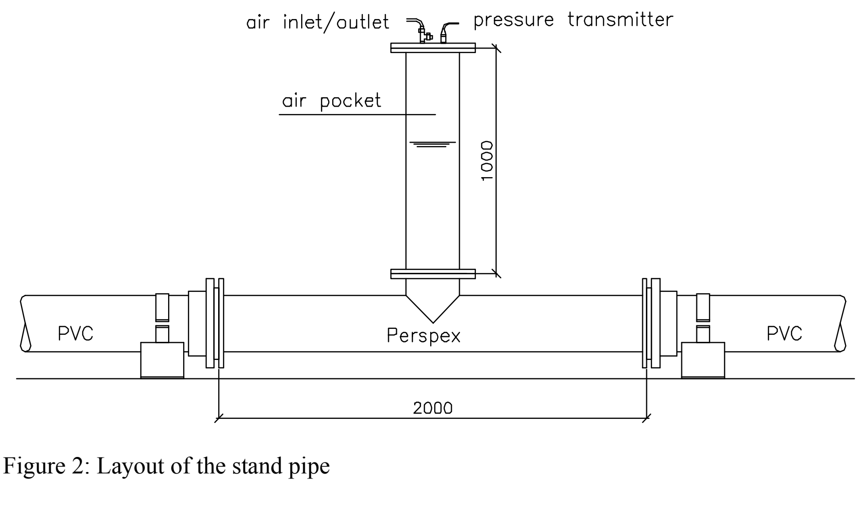

Figure 2: Layout of the stand pipe

Air is supplied by the standard 6 bar pressurised air-infrastructure in the building. A combined mass flowmeter and flow control valve adjusts the airflow to its set value. Since the air flowmeter measures mass, the output gives 'nl/min', i.e. a volumetric flow rate at normal conditions (101325 Pa and 0 °C).

The facility incorporates the following instrumentation.

	range	uncertainty
EMF DN125	0 – 100 l/s	< 0.25%
Gas flowmeter	1 – 50 nl/min	< 0.5 %
Four absolute pressure transmitters	0 – 3 bara	< 0.1 %
Four pressure differential transmitters	ranging from 1.20 mbar – 2.5 bar	< 0.1 %
Temperature transmitter	3 to 100 °C	< 0.1 °C

The facility comprises tappings at 14 locations, where 4 absolute pressure transmitters and/or 2 differential pressure transmitters can be applied. In order to prevent air from disturbing the pressure measurements, the tappings are located at the bottom of the pipe. The temperature transmitter is located at the reservoir in order to monitor possible temperature increase caused by the pump.
All signals are recorded using an automated data-acquisition system in which the sampling frequency can be adjusted manually ranging between 0 and 10 kHz, the acquired data are stored on a hard disk.

Numerical simulation of pressure wave reflection

An example is given for the reflection of the pressure wave in the experimental set-up, with and without an air pocket. A numerical model of the experimental set-up is made using a software package for waterhammer simulations (Wanda 3.50). The excitation of the pressure is caused by the pump which speed is decreased from 1470 rpm to 700 rpm in 0,5 second. The underpressure wave moves into the system and reflects on the end of the system or any air pockets that is in the system. The pressures are taken from 150 m and 401 m downstream of the pump, one upstream of the air pocket and one downstream.

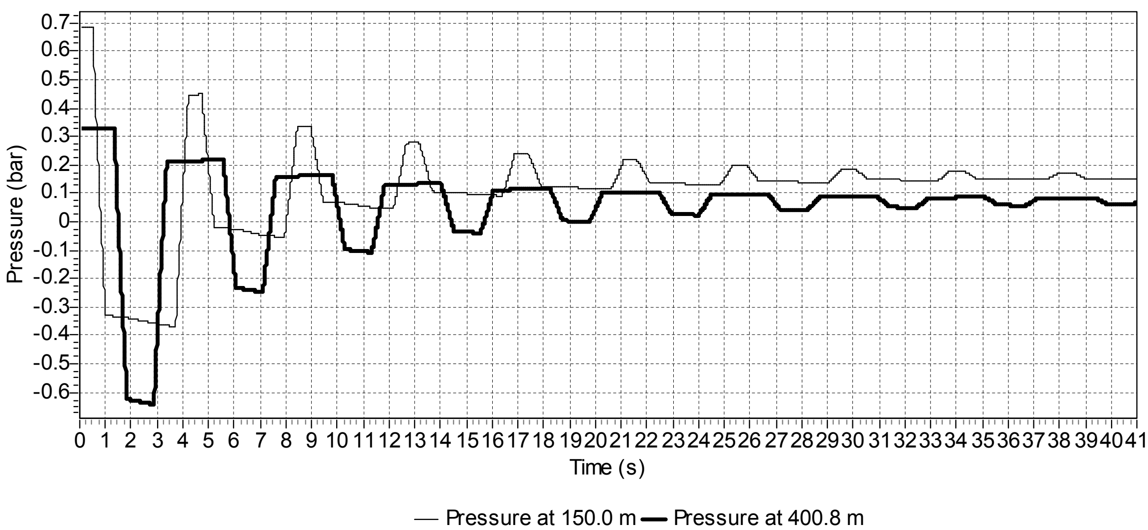

Figure 3: Time series of the pressure at two locations, no air pocket

Figure 3 shows the time series of the pressure at locations 150 and 401 m downstream of the pump. The reflection period and the length of the system gives the appearing wave speed. Figure 4 shows the power spectrum of the pressure time series. It shows peaks at the first harmonic and second and third harmonics which depends on the shape of the periodic signal. Table 1 shows the frequencies with the high energy power levels and the corresponding wave speed. For the pure water simulation the resulting frequency is 0.2380 Hz which corresponds to a period of 4,201s. The wave speed calculated from the simulation is 300 m/s which is a bit higher than the simulation wave speed of 298.6 m/s. The difference is within the resolution of the frequency of the power spectrum. The power spectrum also shows peaks at higher frequencies. These frequencies occur from the particular shape of the pressure time series. These harmonics have values that are n-times the first harmonic.

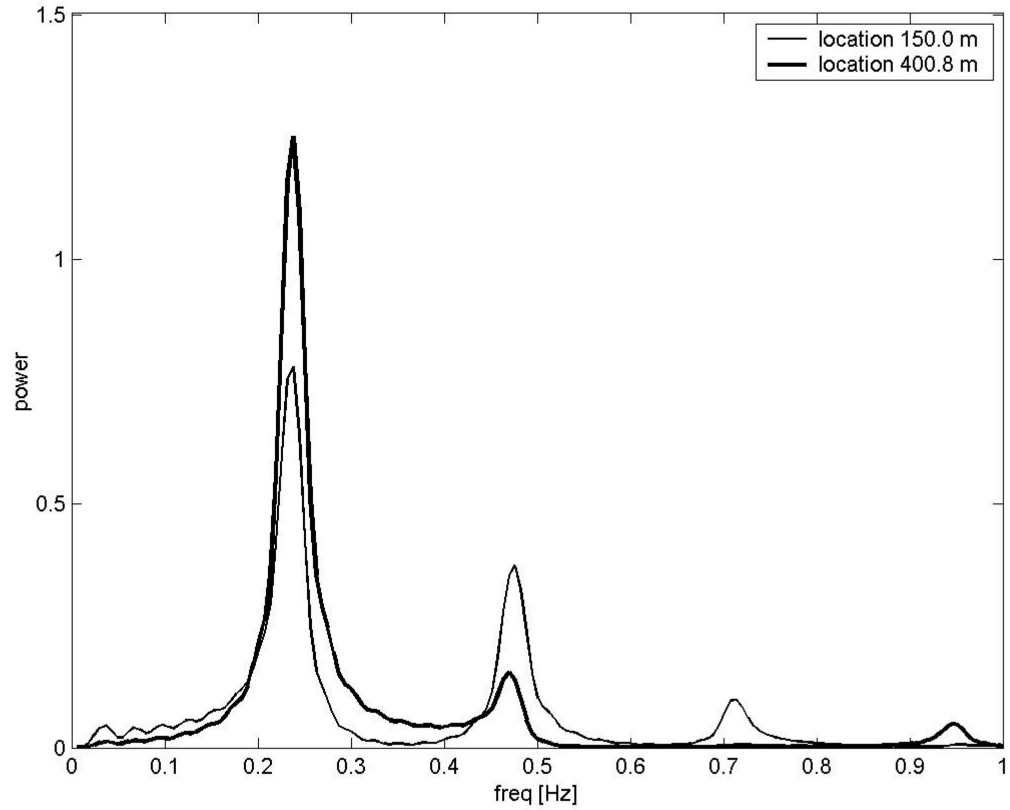

Figure 4: Power spectrum of the frequency of the pressure time series, no air pocket.

Table 1: Frequency values of the power spectrum peaks and corresponding wave speed, no air pocket

location 150 m		location 401 m	
frequency [Hz]	corresponding wave speed [m/s]	frequency [Hz]	corresponding wave speed [m/s]
0.2380 (1^{st})	300 m/s	0.2380 (1^{st})	300 m/s
0.4761 (2^{nd})	600 m/s	0.4700 (2^{nd})	592 m/s

Figure 5 shows the pressure times series in the case where a standpipe is filled with 12,4 l of air at 255 m downstream of the pump and the pump is reduced in speed from 1470 rpm to 700 rpm in 0,5 second. Clearly, the pressure shows a different behaviour.

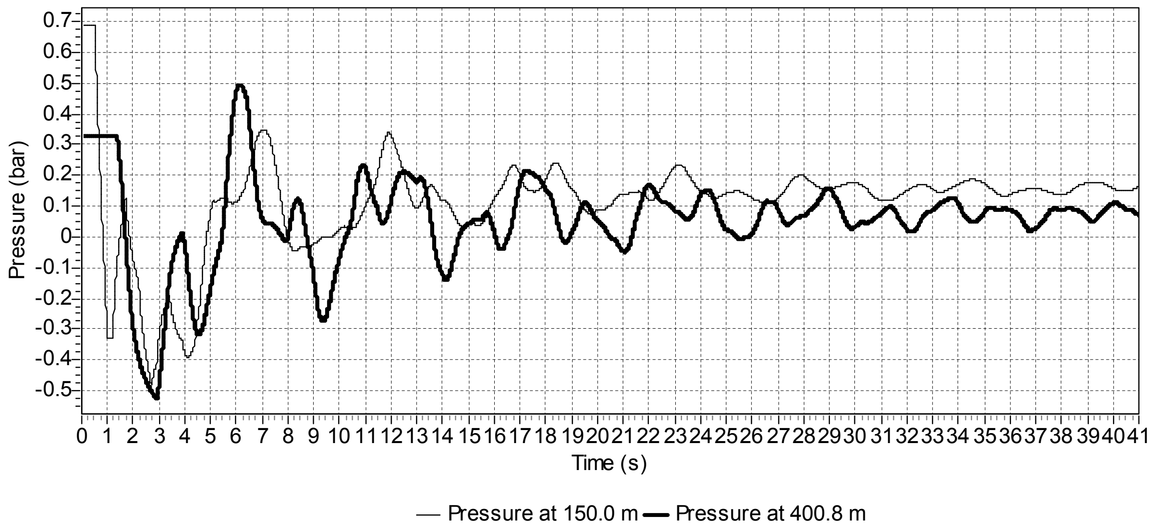

Figure 5: Time series of the pressure at two locations, air pocket at 255 m

Also the power spectrum shows that the pressure time series consists of different frequencies. Figure 6 indicates that the first peak in the spectrum has a lower frequency than in the situation without an air pocket, which means that the reflection period has increased. The occurrence of the air pocket causes a delay in travel time of the pressure wave. Table 2 shows that the first peak in the power spectrum corresponds to frequency 0.1831 Hz, which indicates an equivalent wave speed of 231 m/s. The lower wave speed implies a delay in travel time of the pressure wave.

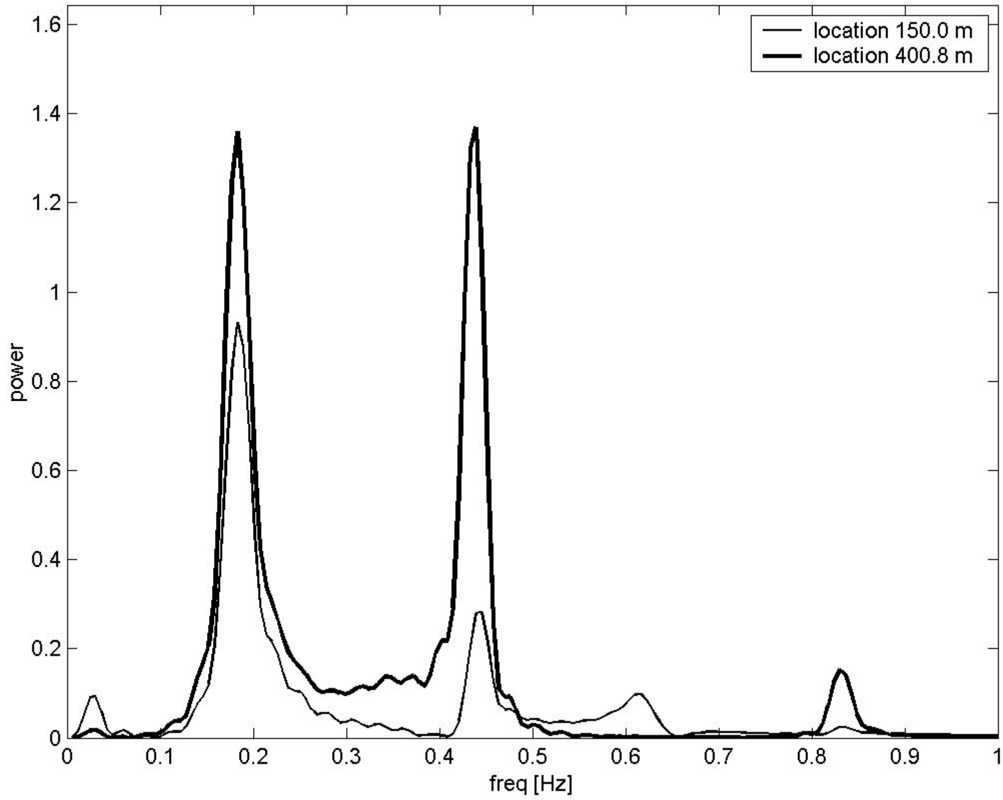

Figure 6: Power spectrum of the frequency of the pressure time series, one air pocket at 255m.

Table 2: Frequency values of the power spectrum peaks and corresponding wave speed, one air pocket

location 150 m		location 401 m	
frequency [Hz]	corresponding wave speed [m/s]	frequency [Hz]	corresponding wave speed [m/s]
0.1831 (1^{st})	231 m/s	0.1831 (1^{st})	231 m/s
0.4456 (2^{nd})	561 m/s	0.4395 (2^{nd})	554 m/s

Discussion

The experimental set-up is designed to produce data for analysing the influence of gas in a pipeline system. The numerical simulations show that frequency content of the pressure time series changes if air is present. Subsequent measurements will be performed in order interpret and analyse the difference in location and volume of the air pocket. The aim of the investigation is to be able to diagnose a pipeline system in a way that the location and the amount of air can be determined.

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