UNIVERSITY OF NIS FACULTY OF MECHANICAL ENGINEERING

THE SIXTH INTERNATIONAL CONFERENCE
TRANSPORT AND LOGISTICS

til 2017

DESIGN OF GRAVITY PIPELINE SYSTEM FOR THE TRANSPORT OF CLEAN DRINKING WATER

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Abstract

Abstract: *Gravitational water supply pipelines are typically designed with interruption (pressure break chambers), in order to maintain the pressure in pipes within acceptable limits. A major disadvantage of such pressure reduction solution is the water exposure to the possible bio-contamination, since the free water surface is in contact with air. Examples of such piping systems can be found in factories for bottling clean natural spring water, where strict rules and requirements with regard to sanitary conditions for water storing and transportation exist. This paper presents possibilities of designing gravity water supply pipelines, where both, the designing and the water quality requirements are satisfied.*

Key words*: Gravitational pipeline, pressure break chamber, valve, orifice.*

1 INTRODUCTION

In gravity systems of public water supply, in order to reduce the pressure in the pipelines, which occurs for small or not existing water consumption, the pressure break chambers (PBC) should be designed and built on the pipeline route.
The water in PBC is in contact with air, which allows its bacteriological contamination. Water is contacting the air in the pipeline sections where the cross-sections is not completely filled with water. Water supply pipeline and PBC should be disinfected by periodic or continious chlorination of water.
In the process of bottling fresh spring water, the transport route from the water spring to the water factory must not be biologically contaminated. Therefore the excess water from the spring should be discharged into the environment, and a supply pipeline should be designed to eliminate all places of possible water-air contact.
To avoid installation of pressure breaking chambers, and, on the other hand, to avoid installing expensive pipes with thick walls, the shut-off valve should be installed in a position which is not much lower than the level of the water sprinkle. Downstream, at the end of the supply pipeline a three-way ball valve is installed, where one way is connected to a factory tank and the second one is connected to a pipeline which drains water into the environment. A three-way ball valve cannot stop the flow through the supply pipeline; it is used for redirecting the water only (to the factory tank or to the environment - in the case of pipeline repair work), therefore in open position of shut-off valve the pipeline is constantly open for water flow.
Factory reservoir is closed and completely filled with water. Excess water flows out from the tank by overflowing.
External geological influences may cause a local deformation and reduction of pipe cross-section, with further increase of the pressure. Therefore, it is it is necessary to install a number of safety valves at appropriate distances of the pipeline.
The basic idea to eliminate interruption chambers in order to avoid the possibility of potential water-air contact. Another possibility of transported water contact with air is the pipeline itself – if there is incompletely filled flow cross-section of the pipeline. To obtain completely filled cross-section and pressurized pipeline, the choice of pipe diameter should be made to obtain the piezometric line above the upper elevation (geodesic) level of the pipeline.
The piezometric line of the pipeline is a line connecting the piezometric height of pipeline cross-sections, while the piezometric height of the observed pipeline cross-section is a (over)pressure height equivalent in the particular pipeline cross-section.
In literature there are not so meny data for calculated such systems (perhaps they are considered as factory's secrets). There are many literatures relating to the principles for calculation and design of water distribution system [1-3], but all these systems require some methods of water post-treatment. In process of bottling clean spring water the main aim is to avoid the need for subsequent purification of water.

2 HYDRAULIC CLCULATION OF A SUPPLY PIPELINE

All water distribution pipelines are calculated using two basic equations: the continuity equation and energy equation. Water is considered as incompressible fluid. For the calculation of the head loss in straight sections of a constant diameter pipeline (D = const.) the Darcy's equation has been used.

$$\Delta h_L = \lambda \frac{L}{D} \frac{c^2}{2g} \tag{1}$$

where: λ – Darcy's friction coefficient, D – the inner pipe diameter, L – the length of the pipeline D=const., c – water flow velocity, Q – volumetric flow rate, g=9,81 m/s^2 – gravity acceleration.
There are many empirical equations for calculation of coefficient λ, for such flow regimes. For such flow regimes, as reliable and simple for using, we recommend the Altsul's formula for calculation of friction coefficient λ [3]:

$$\lambda = 0.146 \left(\frac{68.5}{Re} + \bar{\delta} \right)^{0.25} \tag{2}$$

where, $\bar{\delta} = \delta / D$ - relative roughness of the pipe inner wall, $Re = cD / \nu$ - Reynolds number (ν - kinematic viscosity, $\nu = 1,3 \cdot 10^{-6}$ m^2/s for the temperature value 10^{o}C).

Head loss for pipe elbows, regulation valve and other, can be calculated using an equation

$$\Delta h_{lok} = \xi \frac{c^2}{2g} \tag{3}$$

where ξ - local head loss coefficient.

Therefore, the head loss in pipeline 1-2 is:

$$\sum_{1-2} \Delta h = \sum_{1-2} \Delta h_L + \sum_{1-2} \Delta h_{lok} \tag{4}$$

where, for the full flow cross-sections (under the pressure), friction and local head losses are calculated using equations (1) and (3).

In the head loss calculation using equations (1) and (2) should be calculated with the error of ±3%, also the possibilities of error compensation with a regulation valve (during the pipeline opening).

Required piezometric head at the end of the pipeline is:

$$H_{p_{KC}} = \left(z_R - z_{KC} \right) + \sum_{KC-R} \Delta h + \frac{p_{m.R}}{\rho g} \tag{5}$$

where: $\sum_{0-x} \Delta h$ - head loss from the beginning of the pipeline to the arbitrarily selected pipeline cross-section (x), $\sum_{x-KC} \Delta h$ - head loss from the selected pipeline cross-section x to the end of the pipeline.

In order to obtain a completely filled cross-section of the pipeline, the head losses equilibrium equation (3) must be consistent with the equations (1) and (2) in all cross-sections of the pipeline. Equation (5) is a balance equation of calculated head losses in pipes, for completely filled cross-section.

Theoretically, dividing a pipeline into the larger number of sections, and with appropriate choice of cross-section diameters, we could obtain an adequate pipeline sizing, so that the head loss balance equation is satisfied for completely filled cross-section, in all pipeline cross-sections. Such a solution could be obtained by iterative procedure (changing the length of pipes and their number). Even if the calculation errors, due to uncertainty of selected coefficients used in formulas, are ignored, such a distribution pipeline would be very complicated, with too many different pipes. More importantly, an increased flow-rate could not run through this pipeline, if there is a possibility of connecting another water spring into the system and to increase the capacity of the factory for water bottling.

In practice, the pipeline system is designed with a few pipes with different diameters, and for satisfying head loss equilibrium, an additional losses are made with standardized orifice, whose work cannot be influenced from outside. In some practical calculation examples, the standardized orifices are used according to VDI 2040 German standardization system. This kind of orifice is usually used for flow rate measuring purposes, and therefore, on which there are reliable data on flow coefficients and head loss coefficients.

According to the measured pressure drop in the standardized orifice (Δp_{bl}), fluid flow rate can be calculated by formula:

$$Q = \alpha \cdot \frac{D^2 \pi}{4} \sqrt{\frac{2 \Delta p_{bl}}{\rho}} = \alpha \cdot m \frac{d^2 \pi}{4} \sqrt{\frac{2 \Delta p_{bl}}{\rho}} \tag{6}$$

where: D – the inner pipe diameter where the orifice is built in, d – orifice diameter, $m=(d/D)^2$ – orifice coefficient, α - flow rate coefficient.

In Figure 1. a, dimensions of a standardized orifice are presented, and also in literature [4-6] are given data (diagram or tabular representation) for flow rate coefficients, according to VDI standardization). For inner diameters of pipe $50 \le D \le 1000$ mm i orifice coefficient is $0,05 \le m \le 0,64$.

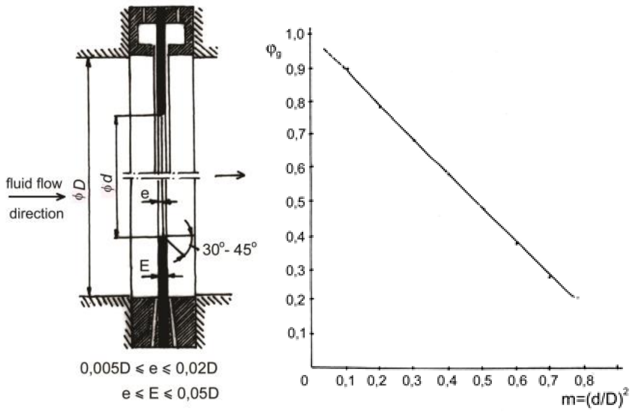

Fig. 1 *a) standardized orifice and b) diagram of pressure loss coefficient*

An orifice pressure loss ($\Delta p_{g.bl}$), i.e. an orifice head loss ($\Delta h_{bl} = \Delta p_{g.bl} / (\rho g)$) can be calculated with a formula:

$$\Delta p_{g.bl} = \varphi_g \cdot \Delta p_{bl} , \quad \Delta h_{bl} = \frac{\Delta p_{g.bl}}{\rho g} = \varphi_g \frac{\Delta p_{bl}}{\rho g} \tag{7}$$

where φ_g - pressure loss coefficient of the orifice.

According to the datasheet given in literature [4], for functional dependence $\varphi_g = \varphi_g(m)$, interpolated function graph $\varphi_g = \varphi_g(m)$ is shown in Figure 1.b.

According to equation (6) and (7), the formula for calculating head loss in standardized orifice can be given in a form:

$$\Delta h_{bl} = \frac{8 \cdot \varphi_g}{g \pi^2 \alpha^2 m^2 D^4} Q^2 = \frac{0,08271 \cdot \varphi_g}{\left(\alpha m \right)^2 D^4} Q^2 \tag{8}$$

Formula (8) can be written in the form of equation (2),

$$\xi_{bl} = \frac{\varphi_g}{\alpha^2 m^2} . \tag{8'}$$

where c is a water velocity in the pipe, where the standardized orifice is built in.

3 EXMPLES OF PIPELINE SYSTEMS

3.1. The supply pipeline from the spring Ropusica to the reservoir in the factory for bottling water near the town of Kolasin)

In this case it was a change of project, according to the previous solution there were two pressure braking chambers, on position KM2+612m and KM4+830m, as it is shown in Figure 2.

By removing five orifices (from positions A, B, C, E and F, in Figure 2), and by replacing the orifice 114.6/23 mm at the position D with another one 114.6/30.5 mm, and obtaining the head loss of about 41 m in the regulation valve, this pipeline could operate with flow rate of 16 l/s, with a completely filled cross-section. In this way the water flow rate could be twice larger, in the case of increasing plant capacity.

We emphasise that the analysis of the previous pipeline design with the pressure breaking chambers, showed that for the flow rate of 8 l/s, a flow at a distance of about 7.1 km was

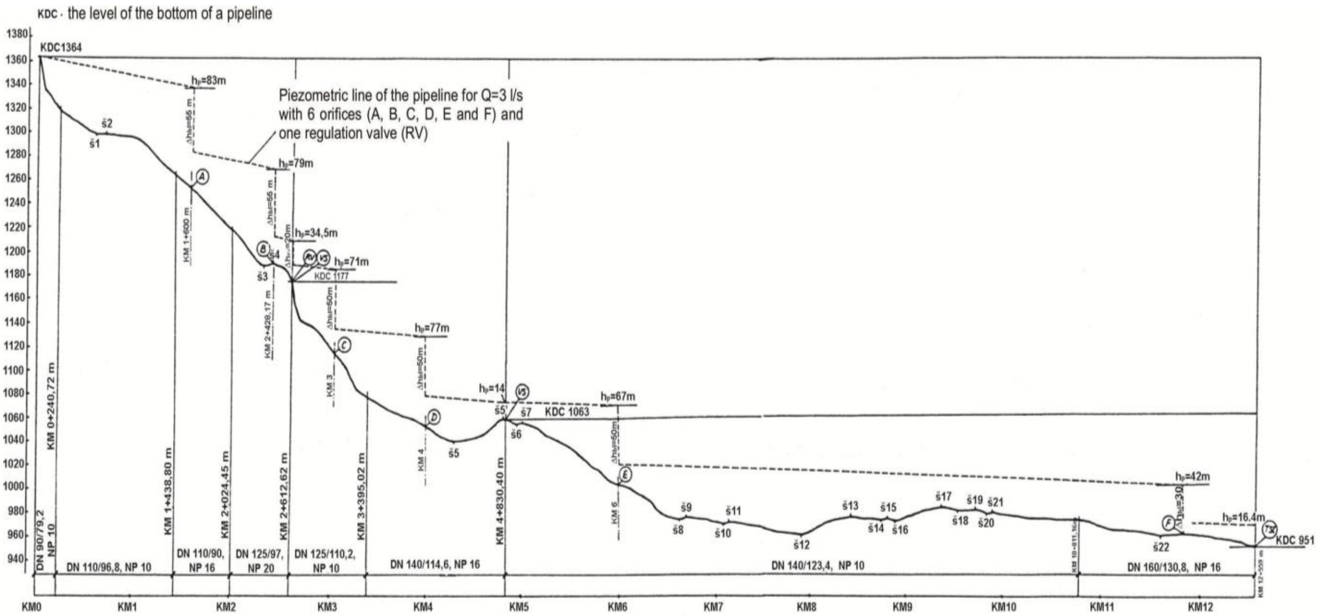

__Fig. 2__ Supply pipeline in the factory near Kolasin

Position in Figure 2:

TSL – Three-way valve at the end of the pipeline.

RV – Regulation valve.

A – Standardized orifice with air release valve (D/d=90/22,4mm).

B – Standardized orifice (D/d=97/22,5 mm), built in in front of air valve (in s4)

C – Standardized orifice with air release valve (D/d=110,2/23,4 mm).

D – Standardized orifice with air release valve (D/d=114,6/23mm).

E – Standardized orifice with air release valve (D/d=123,4/24,7 mm).

F – Standardized orifice (D/d=130,8/26,2 mm), built in in front of air valve (s23).

VS – Safety valve (two of them), with opening pressure 5bar, and water flow rate 8 l/s.

The reconstruction was done with the same, previously calculated, diameters and calculated pressure in the pipeline.

To obtain completely filled cross-section, for a flow rate Q=8 l/s, six orifices are installed, on the positions given in Figure 2.

To establish a flow rate of 8 l/s here is provided flow control valve (regulation valve) to create about 20m head loss. The pipeline is operating and functioning as it was planned.

with incompletely filled pipe cross-section, which is more than a half the total pipeline length (12.6 km).

3.2. The supply pipeline from the spring no. 8 to the water factory in Topli Dol

This supply pipeline was design for water flow rate of Q=5,5 l/s and a relatively short pipeline length which is in total 2 km long, shown in Figure 3.

The pipeline is consists of two sections with different diameter of cross-sections [7]. Pipe diameters are chosen to almost satisfy the head loss balance. At the end of the

The pipeline has two sections of different diameter pipes. Pipe diameters are chosen so that they themselves, on their own, largely balance the loss efforts. At the end of the pipeline, 1 m in front of the three-way valve, the standardized orifice is placed in the position PB (Figure 3), creating the head loss of 25 m.

Position in Figure 3:

8 – Reservoirs of spring number 8

B – A manhole in which is installed an air valve, in the pipeline from the spring no.7 and no.8.

B1 – A building where the pressure breaking chamber is placed, in pipelines from the other springs. There is regulation valve built on the pipeline from the spring no. 8, which operates without pressure break chambers

C – A building where the pressure breaking chamber is placed, in pipelines from the other springs.

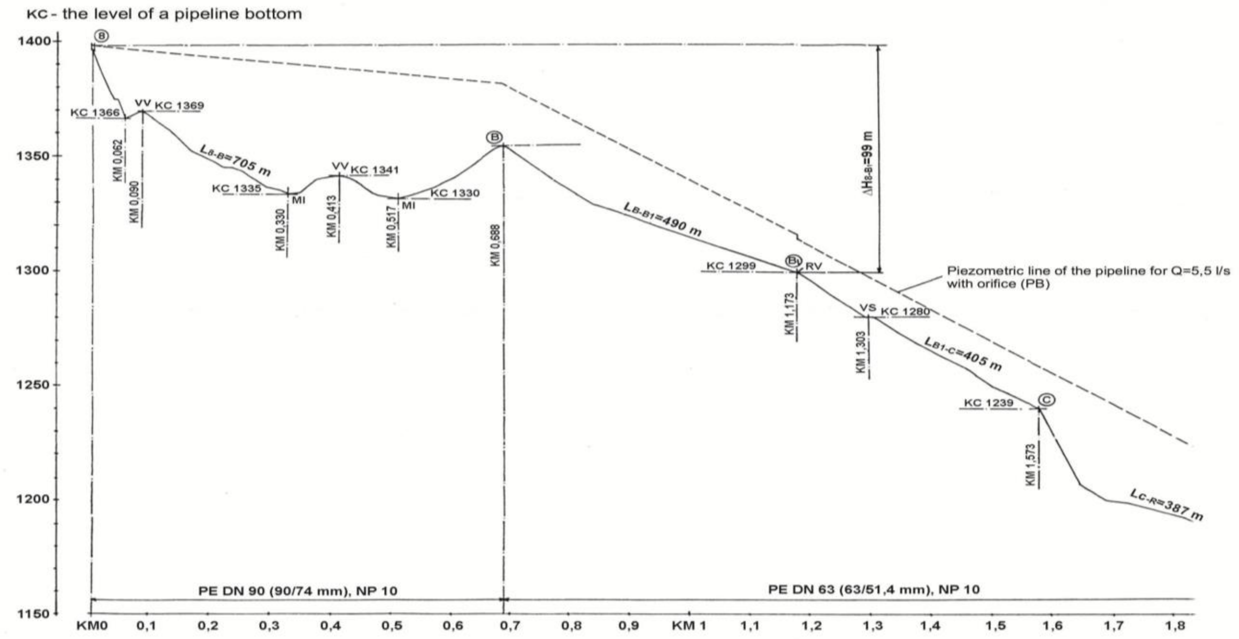

Fig. 3 *Supply pipeline in the water factory in Topli Dol*

R – Reservoir in front of the factory. This is an open reservoir (with atmospheric pressure). There is an overflow limiting the height of reservoir refilling.
TS – Three-way valve at the end of the pipeline.
PB –An orifice, when operating with flow rate Q=5,5 l/s, creates a head loss of 25 m, and is located around 1 m in front of Three-way ball valve.
RV – Regulation valve (for example butterfly valve).
VS – Safety valve (operating pressure 10 bar, flow rate of 5,5l/s). It's located in the manhole on the position KM 1,303, KC 1280.
VV – Air valve, in the manhole on the positions: (KM 0,09, KC 1369), (KM 0,413, KC 1341), (KM 0,688, KC 1354).
MI – Manhole for sludge discharge, positions (KM 0,062, KC 1366), (KM 0,330, KC 1335), (KM 0,517, KC 1330).
Z – Valve for closing the pipeline, at the beginning of the pipeline (after the reservoir).

4 CONCLUSION

These examples show the possibilities of designing the supply pipelines without pressure breaking chambers, in the cases where is crucial to avoid the water-air contact and potential biological contamination during the water transport. This is particularly important in transporting of clean spring water, from the reservoirs to the factory for water bottling.

The absence of interruption chambers (or pressure breaking cambers), for the pressure relaxation in the pipeline, is compensated with standardized orifices, which create an increased head loss in the pipeline.

The standardised orifice is chosen due to its known operating characteristics. Generally all pressure drop devices for which we know operating characteristics (functional dependence of pressure loss coefficient).

Using standardized orifice enable increasing of the water transport capacity (water flow rate in the pipes for the completely filled cross-section of the pipe), by simple replacement of the orifice. This allows the development of water bottling production, with very little additional investment, without changing the large water distribution system.

ACKNOWLEDGMENT

The paper is a part of the research done within the project TR33040.

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