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Head losses induced by filter cartridges in drinking water networks

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Abstract. In the framework of liquid treatment processes, with the aim of ensuring public health security for drinking water or to prevent economic damage, when safeguarding important production processes, major investments have been devoted to research, study and design of innovative products able to respond to market demands, that offer nowadays several solutions.

The present work focuses, specifically, on the filtration of drinking water with filter cartridge systems, with the aim to investigate the effect of their introduction into a hydraulic system in terms of head losses. The problem is particularly important when the cartridge is installed in hydraulic plants characterized by low pressures, in which its insertion can make the pressure levels fall below the minimum limit recommended to ensure the smooth operation of domestic devices. Specifically, the behavior of seven different commercial filter cartridges was analyzed through an experimental analysis conducted in a pilot circuit at the Laboratory of Environmental and Maritime Hydraulics (LIDAM), University of Salerno. Experiments have been performed here in different operating conditions, detecting pressure data in different points through piezometric gauges. The analysis provided some information useful in the choice of the proper cartridge in low-pressure distribution systems.

Keywords: drinking water networks, filter cartridges, head losses, laboratory experiments

1. Introduction

Water treatment is of increasing importance nowadays, because of the pollution and environmental degradation due to the progressive industrialization and deplorable human actions. It has two important purposes: 1) use water that otherwise would not fit some specific purpose; 2) discharge waters, made polluted and polluting by specific processes and operations, at a uninjurious rate of impurities.

In recent years increasingly efficient and innovative water filtration systems have been adopted. This study is focused on the drinking water filtration and, in particular, on the experimental analysis of the effects, in terms of head losses, produced by the installation of a filter cartridge in a drinking water plant. These effects, in fact, are not negligible and may determine pressure values not compatible with those required for a proper functioning of some electro-mechanical elements present in domestic water systems. In the case of a civil user, for example, if the pressure at the inflow of the plant is slightly greater than 1 bar and the user installs a filtration system, for example with wire-wound cartridge, capable of producing a pressure loss of the order of several tenths of bar, the operating pressure may fall below the minimum limit of 0.8 bar recommended by the domestic equipment manufacturers (dishwashers, washing machines, boilers, etc.) to ensure their smooth functioning.

The analysis of the literature on this topic appears quite poor (Kanade *et al*. 2005; Pawlowicz *et al*., 2006; Tomaszewska *et al*., 2016). Therefore, to shed more light on this subject, a pilot circuit was designed and built at the Laboratory of Environmental and Maritime Hydraulics (LIDAM), of the Department of Civil Engineering (DiCiv), University of Salerno, to perform experiments aimed at giving information about the head losses produced by filter cartridges.

In particular, in this study seven different commercially-quite popular filter cartridges were analyzed.

During the experiments, pressures were measured both in the original system (i.e. in the absence of cartridges) and in the presence of each of the seven cartridges with three different operating scenarios and with three different flow rates.

The acquired data were then processed to evaluate the performance of the piezometric line of each simulated circuit and the pressure losses produced by each filter cartridge.

In the following, first the different filtration modalities with the selected cartridges are briefly described. The pilot circuit designed and built in the laboratory is then described, along with the operating conditions and the related components. Finally, results are given and some conclusions are drawn in terms of suggestions for the technical selection of the proper cartridge in a circuit.

2. Filtration cartridge systems

Among the cartridge filtration systems, it is possible to find on the market two distinct categories:

1) cartridges for mechanical filtration, useful to separate fluid from any suspended not settleable solids (pebbles, rust and metal chips, etc.);

2) cartridges for water treatment, which instead allow to subtract from the specific fluid particles dissolved in it, such as mineral salts and chlorine.

Several different types of filter cartridges are commercially available, with their own characteristics and therefore more or less suitable for the filtration of specific fluids. Eligibility is recognizable in relation to specific factors: nature of the liquid to be treated, particle size, filtration efficiency, permeability of the filter material, pressure loss, chemical compatibility, thermal stability, cost/benefit ratio, maintenance.

Among the available cartridges, only the seven most popular ones (Figure 1) have been considered in this study, focusing specifically on the pressure drop feature:

1. wire-wound polyester filter;
2. nylon mesh filter;
3. granular activated carbon filters;
4. filter cartridge with crystal polyphosphate;
5. cationic resin filter cartridge;
6. anionic resin filter cartridge;
7. mixed-bed resin filter cartridge.

Each cartridge was analyzed in the function performed when adopted in a given plant, evaluating the behavior in the different operating conditions of the pilot circuit.

2.1. Wire-wound polyester filter cartridge

A wire-wound filter cartridge works for mechanical filtration. It is produced by winding a wire on a central support core, both made of pure polypropylene, very tenacious and non-toxic, that make it suitable also for the treatment of drinking water. The main uses are: protection of boilers, taps, washing machines; pre-filter for pumps, irrigation systems, industrial (chemical, petrochemical, photographic, electroplating, pharmaceutical) installations.

2.2. Nylon mesh filter cartridge

The nylon mesh filter cartridge works for mechanical filtration. The filtration process is in this case direct interception-type: when the flow reaches the filter, this stops particles of diameter smaller than that of its pores. Particles may be also caught from the filter by bridge effect if they are smaller but positioned "sideways" with respect to a pore, or if two or more particles hit a pore at the same time, or if another particle partially occludes a pore, or if surface interactions, such as surface adhesion forces, hydrogen bonds or Van der Waals forces, are generated, making small particles adhere to the inner surface of the pores.

The square mesh is made by weaving a square mesh of polyester wires, tough, resilient to bending, and resistant to chemical and physical agents. Its structure, with a smooth surface, allows a uniform flow, minimizes the risk of occlusion, ensures accurate filtering capacity with a minimum head loss. The filter is easily washable and does not release contaminants.

2.3. Granular activated carbon filter cartridge

A granular activated carbon filter cartridge works for water treatment, because it removes halogenated organic substances, such as trihalomethanes and other DBP (disinfection by-products), pesticides, herbicides, triazines, chlorine and other substances that impart unpleasant odors and flavors, and color.

Activated carbon mainly contains amorphous carbon, which has a highly porous structure and a very large specific area. It is, therefore, able to hold in its interior many molecules of other substances, i.e. it has high adsorbent capacity, which makes it suitable for a wide variety of processes, such as filtration, purification, deodorization and discoloration of fluids. The activated carbon can be produced from almost any organic substance with high carbon content (e.g. wood, coal, peat, coconut, etc.).

This cartridge determines a significant head loss to be considered indispensable if one wants to get the maximum result.

The material of this type of cartridge is non-toxic, then suitable for the treatment of drinking water, but a further disinfection treatment is recommended to remove or disable any eventual pathogenic microorganisms. It is also suitable for non-potable domestic use (anti-chlorine treatment for washing machines, showers and other facilities) and industrial use (food, chemical, pharmaceutical, etc.).

2.3. Filter cartridge with crystal polyphosphate

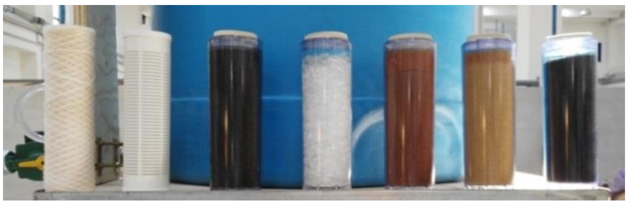

Figure 1. Filter cartridges for domestic use water analyzed in the present work

A filter cartridge with polyphosphate is a cartridge for water treatment, as it protects from the formation of incrustations deriving from limestone and corrosion in the hot and cold water distribution lines.

The polyphosphate also acts as an effective means of protection against corrosion, forming a thin protective film on the surfaces of pipes, coils and water heaters. Pipe corrosion may occur externally (for contact with aggressive soils) and internally (by the action of transported water), determining the thinning and perforation of the wall and altering the composition of water and its organoleptic properties.

The efficiency of this cartridge is the lower between those analyzed here.

2.5. Cationic resin filter cartridge

A filter cartridge in cationic resin works for water treatment, as it softens the water eliminating its hardness.

The cationic resins are solid not-soluble substances, specifically organic macromolecules formed from a crosslinked polymeric matrix with a large number of active functional groups, capable of interchange ions with a liquid, for example water. Cationic resins fix positive ions and anionic resins negative ions. The process consists, basically, in the substitution of calcium and magnesium ions in water, responsible for the scale formation, with sodium ions released from the cation exchange resin. The resins are composed of small balls with a diameter generally between 0.3 and 1.2 mm. On contact with water there is a swelling, with an increase of the volume of about 5%.

This resin is suitable in water softening treatments for industrial, agricultural and domestic purposes, but, if the treatment takes place within specific limits established by law, it can be used also for drinking water treatments.

2.6. Anionic resin filter cartridge

A filter cartridge in anionic resin works for water treatment as this resin is capable of implementing a reversible interchange of ions with a liquid (e.g. water).

The objective is to reduce the presence of anionic mineral salts, such as those containing sulfate, nitrate and chloride ions of the water, substituting these ions with hydroxyl ions released by the anion exchange resin, thus reducing the possibility of compromising the man and plant health.

The sulfate is a major component dissolved from the rain. High sulfate concentrations in drinking water can have a laxative effect if combined with calcium and magnesium. Bacteria, which attack and reduce sulfates, form hydrogen sulfide gas. High sulfate levels may also be corrosive to the hydraulic system, especially for copper piping.

The nitrate ions are harmless to human health, but they often turn into nitrites, which are toxic, since they bind to hemoglobin in the blood and hinder the oxygenation of tissues and, therefore, can result in respiratory distress and even asphyxiation (blue disease).

The chlorides are widely distributed in nature in the form of sodium, potassium and calcium salts. Dissolved in water, they increase its electrical conductivity and the fixed residue; in high concentrations can affect the water taste and flavor and cause pipe corrosion.

2.7. Mixed-bed resin filter cartridge

A mixed-bed resin filter cartridge works for water treatment, since it is a mixture of anionic and cationic resins able to remove simultaneously both the cations (exchanged with hydrogen ions) and the anions (exchanged with hydroxyl ions) from water.

This cartridge can be used for the production of demineralized water used in batteries, irons and for all uses requiring water free of salts (laboratory, chemistry, electronics, photography, etc.). If suitably controlled, the produced water may be also used for human consumption.

The demineralization is a chemical-physical water treatment for the removal of all or part of the dissolved salts. The cationic resin is able to exchange with all the cations present in the water releasing hydrogen ions. In this way water contains only acids (anions) relative to dissolved salts; if it comes in contact also with anionic resins, the final result will be water free of anions and cations and therefore completely free of salts.

3. Laboratory setup

3.1. Equipment

A hydraulic circuit (Figure 2) was realized and sized with the aim to simulate in laboratory a generic civilian user with a cartridge filtration system, in order to calculate the head losses along the pipes and in correspondence of the filter. To make the experiment as realistic as possible, pipes with commercially popular materials and diameters were adopted.

The experimental circuit consists essentially of:

1) a polyethylene tank with capacity of 300 l;

2) an electronic circulation pump with maximum head equal to 6.9 m;

3) a single-jet water meter;

4) a housing element with interchangeable filter cartridges;

5) a galvanized steel pipe with diameter $\phi 20$;

6) a pipe in multi-layer material with diameter $\phi 16$;

7) a pipe in multi-layer material with diameter $\phi 20$.

The two reaches in multi-layer material, with diameters $\phi 16$ and $\phi 20$ respectively, are linked in parallel and used one at a time, thanks to seven ball valves posed along the circuit, which also regulate the flow rate. The analysis, in fact, has been conducted in different operating conditions.

3.1. Experiments

The circuit can be used, thanks to the system of valves, in different modes. Three scenarios are considered in the presented experiments:

- Mode 1: bypass of the multi-layer reaches and use of the only short galvanized reach of the circuit;

- Mode 2: use also of the long reach of the circuit in multy-layer material with diameter ϕ16;

- Mode 3: use also of the long reach of the circuit in multy-layer material with diameter ϕ20.

In each circuit (modes 1, 2 and 3) experiments have been performed with three different values of discharge (Q_{min}, Q_{int} -intermediate- and Q_{max}), depending on the operating modes of the pump, in the conditions of no filter cartridges (NF) and introducing one at a time the seven filter cartridges listed in section 2, each time inserted in the proper plastic container.

When the circuit is operating, it is possible to detect, by the pressure gauges for direct reading of the liquid column, the pressure values in different detection points, selected to permit the calculation of the head losses in the filter element and along the pipe (also by plotting the acquired data on proper diagrams). Each measurement have been repeated five times in order to check the repeatability of the experimental tests. Next results are therefore expressed as ensemble mean values.

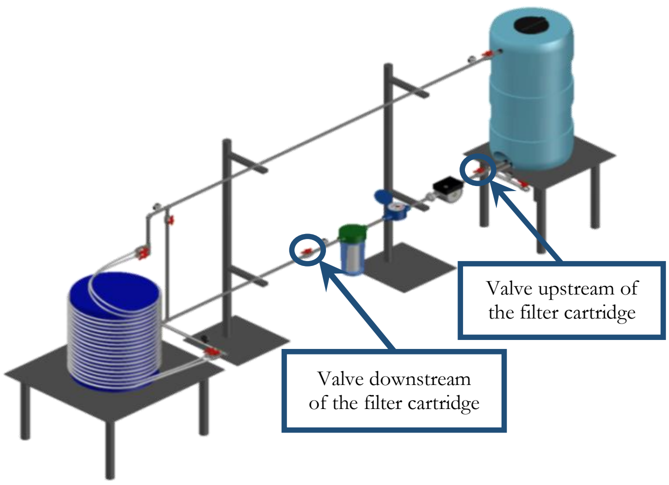

Figure 2. Sketch of the pilot circuit adopted for the laboratory experiments

4. Results

Results of the experiments are summarized in Table 1 in terms of head losses ΔH (in m) and corresponding discharges (in l/s) in the conditions of no filter cartridges (NF) and introducing one at a time the seven filter cartridges for the three operating conditions (modes 1, 2 and 3) and the three different values of discharge. The values have been averaged starting from the acquisitions of the repeated tests.

Figure 3 also shows for each operating mode the plots of head losses as functions of discharges, again in all the considered scenarios.

These graphs permit to highlight some outcome. It is possible to notice how in all the conditions for low values of discharges the corresponding head losses increases in a linear way. However, for most of the filters, once exceeded a threshold value of Q, the head loss keeps constant or grows more slowly. In each curve of the pencil, two zones can be observed: a high-gradient one, with a fast increase of the head losses, and a low-gradient one, with a slow head loss increase. This can be explained by considering that before the discharge threshold value, when the pump passes from a value of discharge to a higher one, it produces an increase of the total head which compensates the increase of the distributed head losses. However, these losses depend on the squared discharge; for this reason, when Q changes from Q_{int} to Q_{max}, the manometric head grows faster than the distributed head losses.

The curve obtained with no filter (NF) cartridge in the circuit is the lower in the graph and it represents, therefore, a sort of threshold borderline: as expected, in fact, the introduction of a filter cartridge in the plant always produces a concentrated pressure drop and a consequent head loss which is not observe when the filter cartridge in not inserted in the circuit.

5. Conclusions

In this work some experimental results in terms of head losses produced in drinking water networks by filter cartridges are presented. Different operating conditions (three circuits and three discharge values) are considered. The results offer interesting suggestions about the choice of the proper cartridges in low-pressure distribution systems.

Table 1. Ensemble average of head losses ΔH (in m), bold typed, for each filter (first raw refers to the void cartridge) and operating condition. Corresponding ensemble discharge values, italic styled, are expressed in l/s.

	Mode 1			Mode 2			Mode 3		
	Q_{min}	Q_{int}	Q_{max}	Q_{min}	Q_{int}	Q_{max}	Q_{min}	Q_{int}	Q_{max}
	ΔH	**ΔH**	**ΔH**	**ΔH**	**ΔH**	**ΔH**	**ΔH**	**ΔH**	**ΔH**
NF	*0.119*	*0.181*	*0.254*	*0.053*	*0.125*	*0.137*	*0.071*	*0.120*	*0.155*
	0.936	**1.520**	**1.982**	**1.522**	**2.122**	**3.159**	**1.363**	**2.016**	**2.93**
1	*0.086*	*0.090*	*0.200*	*0.037*	*0.038*	*0.070*	*0.068*	*0.083*	*0.127*
	2.460	**3.890**	**3.918**	**2.791**	**4.188**	**4.273**	**2.597**	**4.079**	**4.097**
2	*0.118*	*0.133*	*0.268*	*0.048*	*0.050*	*0.083*	*0.068*	*0.093*	*0.148*
	1.875	**3.352**	**2.690**	**2.712**	**4.054**	**4.223**	**1.901**	**3.481**	**3.753**
3	*0.065*	*0.071*	*0.127*	*0.035*	*0.038*	*0.063*	*0.044*	*0.048*	*0.078*
	2.850	**4.381**	**4.505**	**2.993**	**4.466**	**4.664**	**2.993**	**4.452**	**4.601**
4	*0.119*	*0.124*	*0.227*	*0.049*	*0.063*	*0.083*	*0.068*	*0.094*	*0.125*
	2.362	**3.645**	**4.146**	**2.680**	**3.987**	**4.634**	**2.402**	**3.904**	**4.236**
5	*0.094*	*0.099*	*0.163*	*0.043*	*0.046*	*0.077*	*0.058*	*0.061*	*0.103*
	2.796	**4.047**	**4.767**	**2.959**	**4.376**	**5.072**	**2.846**	**4.284**	**4.954**
6	*0.037*	*0.039*	*0.064*	*0.024*	*0.028*	*0.043*	*0.030*	*0.033*	*0.053*
	3.154	**4.621**	**5.480**	**3.285**	**4.844**	**5.628**	**3.230**	**4.754**	**5.557**
7	*0.035*	*0.038*	*0.063*	*0.025*	*0.028*	*0.043*	*0.031*	*0.033*	*0.054*
	3.045	**4.602**	**5.374**	**3.177**	**4.735**	**5.484**	**3.127**	**4.663**	**5.403**

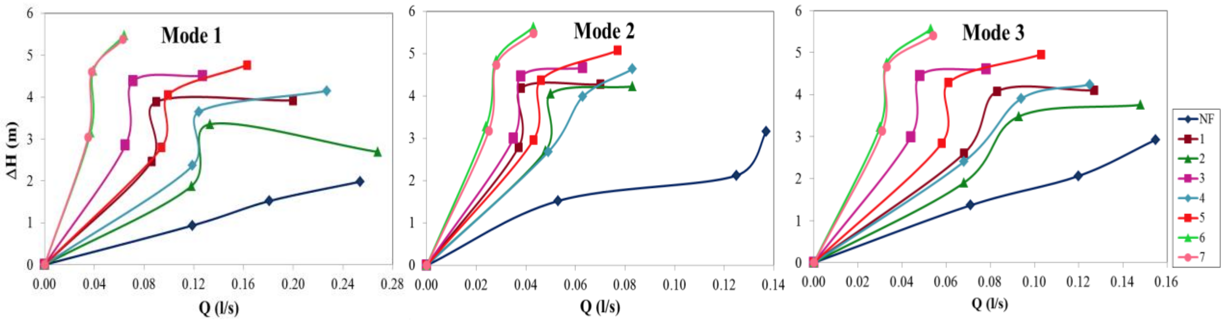

Figure 3. Results of all tests in terms of head losses as functions of discharges for the three different circuits (modes 1, 2 and 3, respectively) in the conditions of no filter cartridges (NF) and introducing one at a time the seven filter cartridges

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