Prospects for the use of "smart" pipe in pressurized water systems in the aspect of effective water resources management

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Abstract. The development of water management in the context of global water shortages and, at the same time, the increased demand of the population and industry for water requires new innovative solutions that will ensure a stable supply of the population, industry, agriculture and energy with the required amount of water. The main and indispensable elements for ensuring the supply of the required amount of water are pipes that are installed in pressure systems. The current types of pipes used in the water industry cannot constantly track trends in the distribution of the amount of water, which change over 24 hours and 365 days. This article will introduce a new concept for the development of pipes used in pressure systems that will increase the performance of water systems and provide significant savings in clean water.

1. Introduction to the issue

Water resources management is an important aspect of sustainable development of territories [1]. Water-related issues are of concern to academics around the world [2]. Due to rapid urbanization and extreme weather conditions, water management problems are associated with increased floods, overexploitation of groundwater, water scarcity in crowded areas and agricultural production, depletion of rainwater resources and pollution of water basins [3-5]. To achieve sustainable use of water resources, an integrated, consistent and forward-looking national policy is required [6].

The need to move water under pressure is increasing in today's world. To reduce the environmental impact of pressurized water systems and increase the efficiency of their operation, in the development of these systems, it is necessary to take into account the flexibility of the layout, safety, quality service, production control [7, 8].

Pressurized water systems that distribute drinking water and water for other purposes mainly cover three water sectors, namely industrial water supply, agricultural irrigation systems [9], and hydropower systems for electricity generation. These systems are increasingly operated to the extreme limits of use. The amount of water that needs to be taken and distributed to the points of final consumption is determined in accordance with real hydraulic calculations. With increasing losses of water in pipelines, the dimensional accuracy of pipelines is relativized as there is a constant demand for new volumes of water that must be collected and distributed through pipelines in pressure systems to meet these constant needs.

This publication discusses a new concept for the development of water pipes based on materials with memory properties that will enable efficient use and saving of water.
2. The main parameters of water supply systems
Pressurized water pipelines are designed for long service life, which ranges from 30 to 50 years. But in the practice of water management there are examples of pipeline operation for more than 50 years. In pressure systems (pipelines) during their operation at different times of the day and seasons, the volumes of water consumption are not the same. For the correct sizing of pressure systems, it is necessary to accurately determine the input parameters, the end result of which is to determine the diameter of the cross-section of the pipeline.

In water supply systems the input parameters are:

1. Number of inhabitants in the initial and final period of exploitation of the water supply system, Np and Nk.
2. Water supply Norm, \( Q_0 \) (l/day (h)).
3. Coefficients of daily and hourly unevenness, \( a1 \) and \( a2 \).
4. Volume of water required to be distributed in the water supply system on a daily, monthly and annual basis, \( V \) (m\(^3\)).

In irrigation systems the input parameters are:

1. Size of agricultural land to be irrigated, \( A \) (ha).
2. Irrigation rate-Gross rate, \( M_b \) (m\(^3\)/ha/ year).
3. Irrigation rate, \( M \) (m\(^3\)/ha).
4. Hydromodule of Irrigation, \( q \) (l/s/ha).

In hydropower systems the input parameters are:

1. Annual planned electricity production, \( E \)-year (GWh).
2. Installed power of turbines, \( N \) (MW).
3. The useful volume of water in the storage space, \( W \) (106 m\(^3\)).

All types of pressurized water systems have a common parameter, namely the required volume of water on a daily, monthly and annual basis, which should be properly distributed to the end users.

Unstable flow in pressure systems due to irregular distribution of water through pipelines, which essentially act as linear reservoirs, leads to the fact that at certain times they accumulate more water than necessary. At such times, the pressure in the pipelines increases and they are at risk of water hammer. The consequences of water hammer in pipelines are always serious pipeline failures.

3. Analysis of the dimensioning of water supply systems
The pipelines that are part of a pressure system are usually selected at the last stage of development. Pipeline parameters are usually determined based on the experience of previously developed pressure systems and professional literature, which does not always take into account the real environmental conditions in which new water supply systems will operate.

In the dimensioning of the water supply systems, which are usually oversized, considerably larger values of the input parameters are taken into account for the water supply norm \( Q_0 \) (l/day/h) and for the coefficients of daily and hourly unevenness (\( a1 \) and \( a2 \)).

The size of the water supply rate directly affects the size of the pipelines, that is, the diameters (profiles) of the primary and secondary water supply network. Determination of the values of the coefficients of daily and hourly unevenness is also important in this case. In addition, the duration of the operation of the pumps in the time interval 0-24 hours has a great influence on the operation of water pipelines.

With the executive analyzes of theoretical or hypothetical water supply networks where the following ideal input data are taken:
1. Equal distribution (density) of consumers (population), in the scope of the water supply network.
2. Equal lengths of consumption strokes between each other.
3. Equal water consumption in all strokes.
4. Different water supply norm that changes after each calculation cycle.

The following results are obtained from the analyzed variants for different values of the Water Supply Norm, which are given in tabular form.

Table 1 shows the different values for \( q_{\text{max}} \) / day, \( q_{\text{max}} \) / h and \( q_{\text{min}} \) / h, and for the value of the coefficients of daily and hourly unevenness \( a_1 = 1.3 \), \( a_2 = 1.3 \), \( a_2' = 0.9 \).

| \( N_k (z) \) | \( Q_0 \) (l/day/h) | \( q_{\text{max/day}} \) (l/s) | \( q_{\text{max/h}} \) (l/s) | \( q_{\text{min/h}} \) (l/s) |
|----------------|------------------------|-----------------|-----------------|-----------------|
| 4800           | 150                    | 10.83           | 14.083          | 9.75            |
| 4800           | 200                    | 14.44           | 18.78           | 13.00           |
| 4800           | 250                    | 18.05           | 23.47           | 16.25           |
| 4800           | 350                    | 25.27           | 32.86           | 22.75           |
| 4800           | 500                    | 36.11           | 46.94           | 32.50           |

The dimensions of the pipelines \( D \) (mm) are given in Table 2. The calculations in Table 2 refer to water flow distribution (q) when operating the pumps for 24 hours.

| \( Q_0 \) (l/day/h) 24 hours | \( q \) (l/s) | \( V \) (m/s) | \( A \) (m\(^2\)) | \( D \) (mm) |
|-----------------------------|--------------|--------------|-----------------|-------------|
| 150                         | 11.25        | 0.0125       | 150             |
| 200                         | 14.86        | 0.0165       | 150             |
| 250                         | 18.47        | 0.0205       | 200             |
| 350                         | 25.69        | 0.0285       | 200             |
| 500                         | 36.53        | 0.0406       | 250             |

Of course, the diameters of the supply pipelines change according to the size of the water supply norm, which plays a big role in the dimensioning, but also the duration of the operation of the pumps, which affects the size of the pressure pipelines, should be taken into account. Table 3 shows the calculations for flow distribution according to the already defined water supply norms, but when the pumps are running for 20 hours.

| \( Q_0 \) (l/day/h) 20 hours | \( q \) (l/s) | \( V \) (m/s) | \( A \) (m\(^2\)) | \( D \) (mm) |
|-----------------------------|--------------|--------------|-----------------|-------------|
| 150                         | 13.50        | 0.015        | 150             |
| 200                         | 17.83        | 0.0198       | 200             |
| 250                         | 22.17        | 0.0246       | 200             |
| 350                         | 30.83        | 0.0343       | 250             |
| 500                         | 43.83        | 0.0487       | 250             |

Table 4 shows the same condition for the calculations, but at the pump for 16 hours.
From the previously presented calculations, it can be concluded that the diameters of the pressure pipelines do not change drastically, but with a certain increase of the water supply norm, the diameter of the pressure pipelines changes.

**Table 4.** Dimensioning of pipelines during 16-hour operation of pumps.

| Q_o (l/day/h) | q (l/s) | V (m/s) | A (m²) | D (mm) |
|--------------|--------|--------|--------|--------|
| 150          | 16.875 | 0.01875| 200    |
| 200          | 22.29  | 0.0247 | 200    |
| 250          | 27.71  | 0.031  | 200    |
| 350          | 38.54  | 0.0428 | 250    |
| 500          | 54.79  | 0.0608 | 300    |

The following graphical applications (Figure 1) show the change in the diameter of the pressure pipes D (mm) depending on the change in the water supply rate Q_o (l / day / h) with continuous operation of the pumps for 24, 20 and 16 hours. In the last two cases, the pumps are blocked.

![Graph showing the change in diameter of pipelines](image)

**Figure 1.** The change in the diameter of the pipeline under water pressure depending on the water supply norm.

The change in pipe diameters is obvious at different rates of water supply, as well as at different times of pump operation. The greatest differences in the diameters of pressure pipelines are obtained when the pumps are operated for 16 hours, and naturally, at higher rates of water supply over Q_o = 250 (l / day / h), differences in the diameters of pressure pipelines are observed.

From the attached hydraulic analyzes it can be seen that for the same water supply system with the same configuration with different values of the water supply rate, different diameters of pressure pipelines are required, which are an integral part of pressure systems.

For the same system with the same water flow rate in different pump operation time ranges, different values of the diameters of the supply pipelines are also required.

In the analyzed case, the water supply rate is constant, but the simulation takes into account the optimization of the installed pump power and the volume of reservoirs in settlements.

Hydraulic and optimization of technical parameters of the main elements of water supply systems for a one-zone and two-zone water supply network was carried out, the results of which will be described in another publication. These results formed the basis for the concept of «smart» pipes, which should be considered as part of the concept of «smart» regulation in the sphere of environmental protection and nature [10].
4. Basic concepts for Smart pipes
«Smart» pipes are pipes that do not actually exist at present, and they represent only a hypothesis that is supported by previously analyzed hydraulic calculations, indicating the need for a new approach to technical and technological advances in industrial pipe production.

Flowing pipes that are installed in pressure systems have a constant or fixed cross-sectional diameter of the pipes.

Mathematical modelling indicates the feasibility of introducing a new type of pipe with a variable cross-section, which along a given perimeter will have only the required volume of water, which will be distributed over a certain period of time.

Variable cross-section of pipes can be achieved by using the memory properties of certain types of materials from which the pipes are made. Memory properties of materials are known for polyethylene and its copolymers [11-14], and polyethylene pipes are increasingly used in the practice of water supply. In some cases, pipes can also be made of shape memory alloys based on iron alloyed with aluminium, nickel, manganese, chromium, silicon [15, 16].

«Smart» pipes can have variable cross-sectional diameters within a certain range. According to the results of the mathematical modelling, the difference between the minimum and maximum diameters is 33.33%.

A change in the water supply rate leads to a change in the diameters of the pressure pipelines, which naturally causes problems in the regular water supply.

Mathematical patterns, confirmed by various types of hydraulic modelling, open up possibilities for optimization and determination of the limits of variation of the diameter from the minimum to the maximum size.

The flow rate of water in the pipes is regulated so as not to damage the pipes due to the increased pressure in them.

The results of hydraulic modelling, obtained under various conditions of water consumption, make it possible to determine the initial diameters of the boundaries of the pipelines (Table 5).

Table 5. The possible limit diameters of «smart» pipes at a constant volume of water distribution.

| Distributed volume W (m$^3$) daily, for 24 hours | Initial diameter, F (mm) | Final diameter, F (mm) | Flow from $Q_i$ to $Q_n$ (m$^3$/s) | Speed of water in pipes, V (m/s) | Percentage increase in diameter |
|------------------------------------------------|--------------------------|------------------------|----------------------------------|-------------------------------|-------------------------------|
| 2556.00                                         | 200                      | 600                    | 0.03-0.71                        | 0.94-2.51                     | 33.33%                        |
| 2556.00                                         | 150                      | 500                    | 0.015-0.36                       |                               | 30.00%                        |
| 2556.00                                         | 125                      | 400                    | 0.01-0.24                        |                               | 31.25%                        |
| Average value                                   | 158.33                   | 500                    |                                  |                               | **31.53%**                    |

Thus, using the memory properties of the material, it is possible to produce «smart» pipes with specified characteristics. Practical problem solving of the installation of «smart» pipes in the field is easily solved by installing the pipes in underground concrete channels on metal bearings that will accept all changes in the diameter of the pipes such as accepting expansion and collecting material with dilatation joints.

In the current water supply practice, pipe joints are already being produced that can be joined by pipes of different diameters and pipes made of different materials. Plumbing fittings have a certain range of pipe fittings.

5. Conclusions
Based on all previous mathematical models, namely hydraulic simulations, the following facts have been established:
1. The change in the cross section (diameter) of the pressure pipelines depends on the change in
the value of the water supply norm $Q$, (l/day/h). For a larger norm for water supply, the
diameter of the cross section of the pressure pipelines is larger.
2. The change in the cross section (diameter) of the pressure pipelines depends on the duration of
operation of the pumping stations and the time range of operation of the pumping stations.
3. Only the required volume of water $W$ (m$^3$) to be distributed to the end points of consumption
is constant regardless of the different types of operating loads on the water supply systems.
4. The possibility for production of «smart» pipes gives a real opportunity to solve the existing
problems in the current water supply practice.
5. «Smart» pipes can really be expected to control the distributed water in pressure systems
(precisely designed amounts of water) by significantly reducing water losses in pipelines.
6. Great opportunity to eliminate the occurrence of unstable water movement in pressure systems
and avoid the possibility of hydraulic shock in the pipelines.
7. In order to start experimenting with the production of «smart» pipes, it is necessary to take
into account the memory properties of the materials from which the current types of water
pipes are produced.

The listed conclusions indicate the feasibility of research in the field of production of «smart» pipes
for widespread use in relevant areas should give a serious impetus to experimental testing of new types
of water pipes.

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