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Variation of Hydraulic Resistance in Pressure Pipelines of an Open-Type Hydraulic System

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Abstract

Pressure distributive pipelines with path distribution of fluid are part of various technical systems. Pressure losses at abrupt and smooth pipe reductions are components of total pressure losses in these pipelines. After all, the equalization of fluid distribution along the length of distributive pipelines is achieved, in particular, by reducing their diameter in the direction of flow. Depending on the configuration of the pipe reductions, pressure losses at this pipeline element can vary. For an open-type hydraulic system, a regulatory characteristics of pressure in the pipeline has been obtained with a constant fluid flow in a general form. The influence of measures necessary to change energy losses in the pipeline on the hydraulic resistance of the unregulated section of the pipeline has been taken into account. Options for these measures have been proposed for a pressure pipeline with pipe reduction.

Keywords: hydraulic system; regulatory characteristics; pressure regulation; hydraulic resistance.

1. Introduction

Pressure regulation in short pipelines by means of controlled pipe reduction is widely applied in drip irrigation systems (irrigation), water supply (for the purpose of removing iron hydroxide, free carbon dioxide and hydrogen sulfide from water), wastewater treatment (aeration tanks, air filters, biofilters), fire water supply (sprinkler (automatic) and drencher (semi-automatic) fire extinguishing systems), energy (cooling the circulating water in nuclear and thermal power plants), solar collectors (cold water is supplied to the device by distribution pipelines, heated water is discharged by collector pipelines), tidal ventilation (in production premises with significant heat release and low concentration of harmful substances), agricultural aviation (for spraying plants), water transport (distribution pipelines fill locks and large docks for shipbuilding and repair with water), machine building (fuel distribution mains of multi-cylinder internal combustion engines). The given examples testify that improvement of pressure regulation process is an important problem to be solved.

The main areas of application of pressure distributive pipelines with consecutive structure are considered in [1], [2]. Schemes of their arrangement in a number of technological processes and devices are given, and the principles of operation are described. But attention is not paid to their design features, which can reduce the unevenness of operation along the distributive pipelines. Thus, the equalization of the path distribution of fluid from distributive pipelines is achieved by reducing their diameter in the direction of flow [3]. Examples of such pipelines are the main pipeline of the water distribution device of cooling towers [4] (Fig.1), the irrigation pipeline of drip irrigation [5] (Fig.2), the distributive pipeline of the fire extinguishing system [6] (Fig.3), the pipeline-collector of the pressure hydraulic system for sludge removal from the setting tank [7] (Fig.4). In addition, the distributive pipeline can have a variable cross-section along the length [8], [9] (Fig.5).

Therefore, pressure losses at abrupt and smooth pipe reductions are a component of total pressure losses in distributive pipelines. In this case, pressure losses at the pipeline reductions can be small (Fig.6,a), moderate (Fig.6,b

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and Fig.6,c) or large (Fig.6,d) [10], [26]. This may require variation of pressure losses at these elements of distributive pipelines.

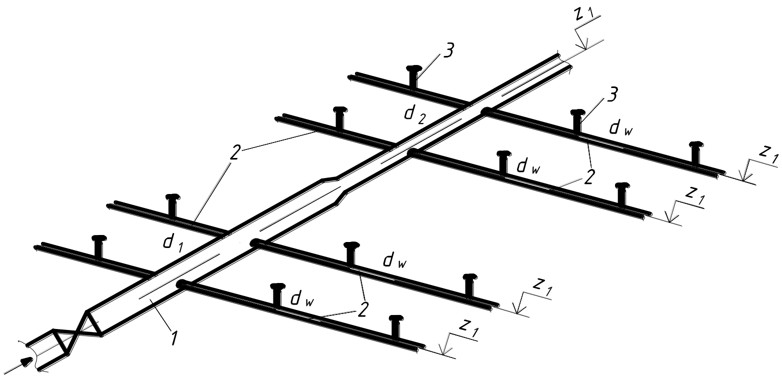

Fig.1. Schematic diagram of the water distribution device of the cooling tower [4]:
1 – main pipeline; 2 – working pipeline; 3 – riser for the sprinkler device.

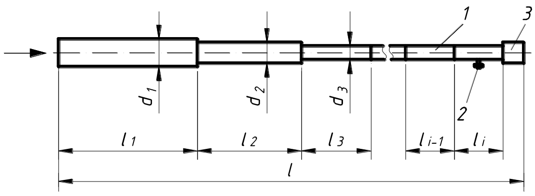

Fig.2. Schematic diagram of the irrigation pipeline of drip irrigation for cleaning from silt [5]:
1 – pipe; 2 – self-flushing device; 3 – plugs; *l* – length of the irrigation pipeline;
l_1, l_2, ..., l_i – length of sections of the irrigation pipeline with a diameter of d_1, d_2, ..., d_i.

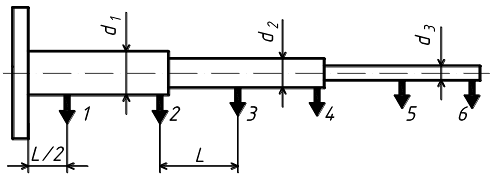

Fig.3. Schematic diagram of a dead-end distributive pipeline of variable diameter [6]:
1…6 – sprinkler; d_1, d_2, d_3 – diameter of sections of the pipeline.

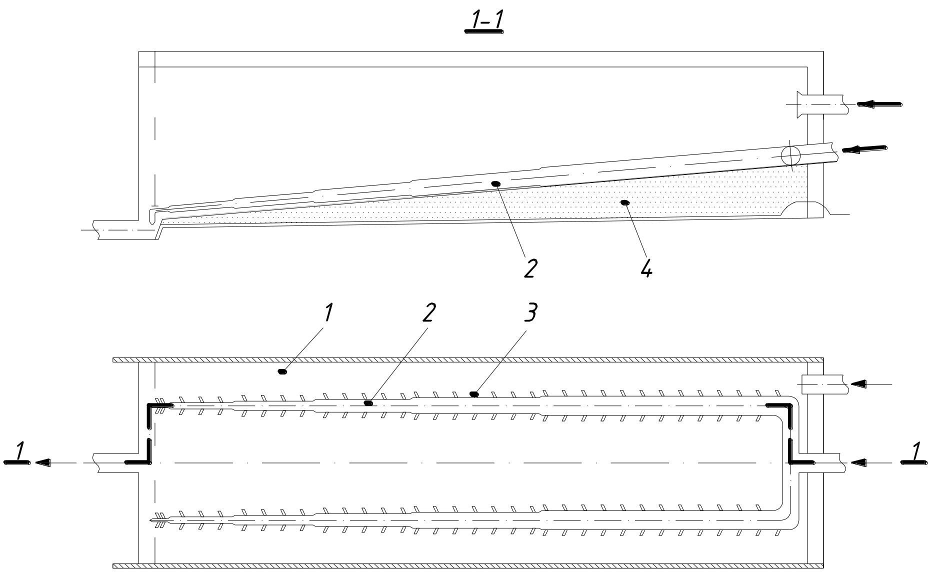

Fig. 4. Schematic diagram of a pressure hydraulic system for sludge removal from the settler [7]:
1 – settling tank; 2 – pipeline-collector; 3 – nozzle; 4 – sludge.

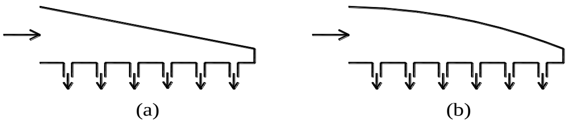

Fig.5. Schematic diagram of pressure distributive pipeline of variable cross section:
(a) with a tapered side wall [8]; (b) with a shaped side wall [9].

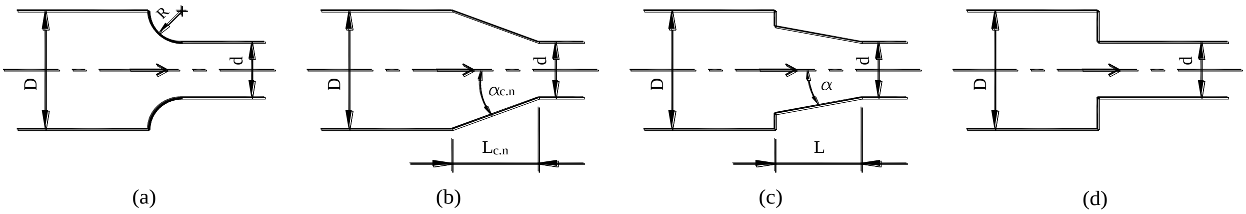

Fig. 6. Schematic diagram of flow at reduction of the cross-sectional area:
(a) abrupt reduction with rounded edges [9], [10], [26]; (b) converging nozzle with rectilinear boundary walls [9], [10], [26];
(c) abrupt reduction with beveled edges [9]; (d) abrupt reduction with sharp edges [9], [10], [26].

2. Analysis of the recent publications and research works on the problem

For a pressure hydraulic system of an open type with variable fluid flow rate, the regulatory characteristics of the flow in the pipeline is presented in [11], [14] and on the regulated section of the pipeline in [12].

For a pressure hydraulic system of an open type with constant fluid flow rate, the regulatory characteristics of the pressure in the pipeline has been considered as follows [13]:

$$\frac{H_{ch}}{H} \approx \frac{(\zeta_{reg}+\alpha)_{ch}+\zeta_{unr}}{\zeta_{reg}+\zeta_{unr}+\alpha}, \tag{1}$$

where H_{ch} and H are the pressure created by the pressure reservoir (Fig.7,a) or pump (Fig.7,b), with measures for changing the energy losses in the pipeline of the pressure hydraulic system, and without these measures respectively; ζ_{reg} and ζ_{unr} are the overall coefficients of fluid resistance of the regulated and unregulated sections of the pipeline, respectively; α is the coefficient of the kinetic energy of the flow.

The pressure created by the pressure reservoir or pump without measures for changing the energy losses is calculated by the formula:

$$H = h + \frac{p_0}{\rho g}, \tag{2}$$

where h is the geometric height (Fig.7,a and Fig.7,b); p_0 is the static pressure on the free surface of the fluid in the pressure reservoir (Fig.7,a) or in the pressure pipeline at the outlet from the pump.

The overall coefficient of fluid resistance is calculated as follows:

$$\zeta_i = \left[\Sigma\left(\lambda \cdot \frac{l}{d}\right) + \Sigma\zeta\right]_i, \tag{3}$$

where ($\lambda \cdot l/d$) is the friction loss coefficient; λ is the hydraulic friction coefficient; l and d are the length and diameter of the pipeline, respectively; ζ is the local hydraulic resistance coefficient.

The resistance coefficient of the regulated section is defined as [14]:

$$\left(\zeta_{reg}\right)_{ch} = \zeta_{reg} \cdot [1 + f(reg)], \tag{4}$$

where *f(reg)* is the regulation function that takes into account measures necessary for changing energy losses in the pipeline of a pressure hydraulic system.

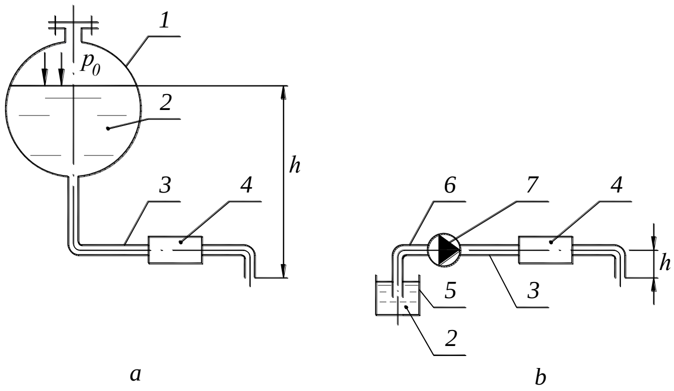

Fig.7. Schematic diagram of control for pressure loss in a hydraulic system with a pressure reservoir (*a*) and a pump (*b*) using a regulated section of the pipeline: 1 – pressure reservoir; 2 – working fluid; 3 – pressure pipeline; 4 – regulated section of the pipeline; 5 – feed reservoir; 6 – tail pipeline; 7 – pump.

The regulatory characteristics of the pressure in the pipeline with constant fluid flow rate is determined by the formula

$$\frac{H_{ch}}{H} \approx 1 + [\alpha_{**} + \zeta_* \cdot f(reg)]; \quad (5)$$

$$\alpha_{**} = \frac{\alpha_{ch} - \alpha}{\zeta_{reg} + \zeta_{unr} + \alpha}; \quad (6)$$

$$\zeta_{**} = \frac{\zeta_{reg}}{\zeta_{reg} + \zeta_{unr} + \alpha}, \quad (7)$$

where α_{**} is a coefficient that takes into account the change in the kinetic energy correction of the fluid flow; ζ_{**} is a regulation coefficient that determines the depth of regulation on the regulated section of the pipeline.

The influence of measures to change energy losses in the pipeline on the hydraulic resistance of its unregulated section is not taken into account in formula (1).

3. Formulation of the goal of the paper

The goal of this work is to justify the possibility of changing the hydraulic resistance of the unregulated section of the pipeline, taking into account the measures necessary to change the energy losses.

4. Presentation and discussion of the research results

The regulatory characteristics of the pressure in the pipeline of the open type pressure hydraulic system with constant fluid flow rate will be written in a more general form as follows:

$$\frac{H_{ch}}{H} = \frac{(\zeta_{reg} + \zeta_{unr} + \alpha)_{ch}}{\zeta_{reg} + \zeta_{unr} + \alpha}. \quad (8)$$

Then, using formula (4), we obtain:

$$\frac{H_{ch}}{H} \approx 1 + [\alpha_{**} + \zeta_{**} + \zeta_* \cdot f(reg)], \quad (9)$$

$$\zeta_{**} = \frac{(\zeta_{unr})_{ch} - \zeta_{unr}}{\zeta_{reg} + \zeta_{unr} + \alpha}, \quad (10)$$

where ζ_{**} is a regulation coefficient that determines the change in the reduced hydraulic resistance coefficient on the unregulated section of the pipeline,

Therefore, to change the energy losses in the pipeline, it is necessary to set the regulation function *f(reg)*. Moreover, the efficiency of regulation will be determined by the sign of α_{**}, ζ_{**}, ζ_* and *f(reg)*.

If the necessary measures to change the energy losses in the pipeline do not affect the hydraulic resistance of its unregulated section, then formula (10) is transformed into formula (5). And in the absence of a change in the kinetic energy correction of the fluid flow, according to formula (6), formula (5) is rewritten as:

$$\frac{H_{ch}}{H} \approx 1 + \zeta_* \cdot f(reg). \tag{11}$$

Thus, for pressure hydraulic systems with pipeline reduction, the effect of measures necessary to change energy losses in the pipeline can be achieved:

1) by changing the geometric parameters of the pipeline with unchanged properties of the working fluid;

2) by changing the properties of the working fluid with unchanged geometric parameters of the pipeline.

In water fire extinguishing systems with reducing cross-section along the pipelines to stabilize the flow of liquid fire extinguishing fluid, hydrodynamically active polymers [15] can be used. In this case, preference is given to pipelines with a smooth change in cross-section.

5. Conclusion

Based on the example of pressure distribution pipelines, for which the equalization of the path distribution of the fluid is achieved by reducing their cross-section in the direction of the flow, methods of changing pressure losses during pipe reduction have been developed. The regulatory characteristics of the pressure in the pipeline of an open type pressure hydraulic system with a constant fluid flow rate has been obtained in a general form. The influence of measures necessary to change energy losses in the pipeline on the hydraulic resistance of the unregulated section of the pipeline has been taken into account. Options for these measures have been proposed for a pressure pipeline with pipe reduction.

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Зміна гідравлічного опору в напірних трубопроводах гідравлічної системи розімкненого типу

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Анотація

Напірні розподільні трубопроводи зі шляховим роздаванням рідини входять до складу різних технічних систем. Втрати напору на різких і плавних звуженнях труб є складовою загальних втрат напору в цих трубопроводах. Вирівнювання роздавання рідини по довжині розподільних трубопроводів досягають зокрема зменшенням їх діаметра в напрямку потоку. Залежно від конфігурації звуження труби втрати напору на цьому елементі трубопроводу можуть змінюватися. Для напірної гідравлічної системи розімкненого типу отримано регулювальну характеристику напору в трубопроводі за сталої витрати рідини у загальному вигляді. Враховано вплив заходів, необхідних для зміни втрат енергії в трубопроводі, на гідравлічний опір нерегульованої ділянки трубопроводу. Запропоновано варіанти цих заходів для напірного трубопроводу зі звуженням труб.

Ключові слова: гідравлічна система; регулювальна характеристика; регулювання напору; гідравлічний опір.