ZESZYT NAUKOWY POLITECHNIKI RZESZOWSKIEJ **Nr 266**
Budownictwo i inżynieria środowiska z. 54 **2009**

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EXPERIMENTAL VERIFICATION OF A NEW METHOD OF CALCULATION FOR PRESSURE DISTRIBUTIVE PIPELINES

ABSTRACT

In comparison with all the known methods of calculation for pressure distributive pipelines (PDP), those developed by Chernyuk,V.V. proved to most exactly agree with results of experiments. Calculated by this technique values of flow rate and of heads of fluid inside PDP practically coincide with experimental data.

KEYWORDS: pressure distributive pipelines, variable mass fluid flow.

1. INTRODUCTION

Pressure pipelines with discrete fluid dispensation along the path are used in different branches of economic activity of the human: irrigation (drip, subsurface, surface); ventilation (discharge systems); metallurgic industry (cooling systems); water transport (distributive lock-feed piping systems and those of large dry docks); water supply and water drainage (distributive pipe systems of purification works, dispersed discharge of sewage) and others. There are different techniques of calculation for pressure distributive pipelines (PDP).

The most perfect of them are based on differential equation of variable mass fluid flow (DEVMFF) [1]. The creator of the theory of motion of variable mass bodies is prof. Meschersky,I.V. (1897). In 1928, prof. Makkaveev,I.V. for the first time deduced the general DEVMFF. In 1937, prof. Nen'ko,Ya.T. obtained the DEVMFF for total stream of fluid and applied it to problems of calculating perforated PDP [2]. For cylindrical PDP DEVMFF is of the form [3]:

$$\frac{\alpha_0\left(v\cos\varphi-2V\right)\cdot dV}{g}+\frac{dp}{\rho g}+\sin\psi\cdot dx+dh_x=0\,, \tag{1}$$

where V is the average velocity of the main stream; v is the same for the flow of an outlet jet; p is the pressure inside PDP; $\sin\psi\cdot dx=dz$ is the geometric head; $dh_x=i_f dx$ is the loss of head along PDP; φ is the angle between the vectors $\vec{v}$ and $\vec{V}$; ψ is the angle of the inclination to horizon (Fig. 1).

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In the existing methods, some variables of DEVMFF are expressed in terms of the main flow $Q_{(x)}$, and the angle $\psi_{(x)}$ of inclination to horizon and is the angle $\varphi_{(X)}$ between the axis of PDP and the direction of outlet jets are neglected. Besides, in the known methods, the magnitude of the friction factor $\lambda_{(x)}$ of PDP and that of the coefficient of the flow rate $\mu_{(x)}$ of outlets (nozzles) are assumed to be constant along the PDP. The non-complete taking into account of design variables of a perforated pipeline and that of hydrodynamic peculiarities of variable mass flow lead to considerable miscalculations [4].

2. TECHNIQUE OF PDP CALCULATION SUGGESTED BY CHERNYUK,V.V. [3]

Doc. Chernyuk,V.V. has suggested a new approach to solving DEVMFF for PDP [3]. It consists in expressing all the variables of DEVMFF in terms of the total operation head $H_{(x)}$ in the PDP. The calculation of PDP made by means of the relations obtained from the solution of DEVMFF practically coincides with the experimental data. The influence of constant or variable magnitudes of all the geometric parameters of PDP, those of kinematic and dynamic characteristics of the main stream and of outlet jets, including the angle $\varphi_{(x)}$ of jet outlets, the angle $\psi_{(x)}$ of inclination, and the change in modes of flow and in laws of resistance along the PDP are taken into account. The deduced relations are good for designing long, intermediate, short, horizontal and inclined PDP. According to the technique suggested by Chernyuk,V.V. [3], the flow rate $b\int_{x_i}^{x_k} H_{(x)}^{1/2}dx$ of the fluid which is dispensed from PDP in its segment $i-k$ whose length x_{i-k} is calculated by means of Equation (2);

$$b_{(i-k)}\int_{x_i}^{x_k} H_{(x)}^{1/2}dx = b_{(i-k)}x_{(i-k)}\left\{H_{(x_i)}^{1/2} + \frac{b_{(i-k)}x_{(i-k)}}{4g\omega_{(x_i)}}\left[\left(2\alpha_o + \alpha\cos\varphi_{(x_i)}\right)V_{(x_i)} - \alpha_o v_{(x_i)}\cos\varphi_{(x_i)}\right] + \right.$$
$$\left. + \frac{1}{4H_{(x_i)}^{1/2}}\left(\lambda_{(x_i)}\frac{x_{(i-k)}}{D_{(x_i)}}\frac{V_{(x_i)}^2}{2g} + 2x_{(i-k)}\sin\psi_{(x_i)}\right)\right\}. \tag{2}$$

The calculation of PDP is made against the stream. The lengths of the segments are taken to be equal to the distances between outlets (nozzles) l_{hole}. The values of total heads are determined according to Formula (3);

$$H_{(x_k)} = \left\{H_{(x_i)}^{1/2} + \frac{\kappa\cdot b_{i-k}x_{i-k}}{2g\omega_{(x_i)}}\times\left[\left(2\alpha_o + \alpha\cos\varphi_{(x_i)}\right)V_{(x_i)} - \alpha_o v_{(x_i)}\cos\varphi_{(x_i)}\right] + \right.$$
$$\left. + \frac{\kappa}{2H_{(x_i)}^{1/2}}\left(\frac{\lambda_{(x_i)}x_{i-k}}{D_{(x_i)}}\frac{V_{(x_i)}^2}{2g} + 2x_{i-k}\sin\psi_{(x_i)}\right)\right\}^2, \tag{3}$$

where $V_{(x_i)}$ is the average velocity of the main stream in the cross-section x_i of PDP (Fig. 1); $v_{(x_i)}$ is the velocity of outlet jet; $b = n\mu\omega_o\sqrt{2g} = const$, $m^{1.5}/s$; $\omega_o = \pi d^2/4$ is the area of the outlet hole (nozzle); d is its diameter; n is the number of holes per unit length of PDP, m^{-1}; D is the inner diameter of PDP.

Friction factor $\lambda_{(x)}$ for PDP is calculated according to the formulae for $Re_{(x_i)} \le 2320$ (laminar flow):

$$\lambda_{(x_i)} = \frac{64}{Re_{(x_i)}}; \tag{4}$$

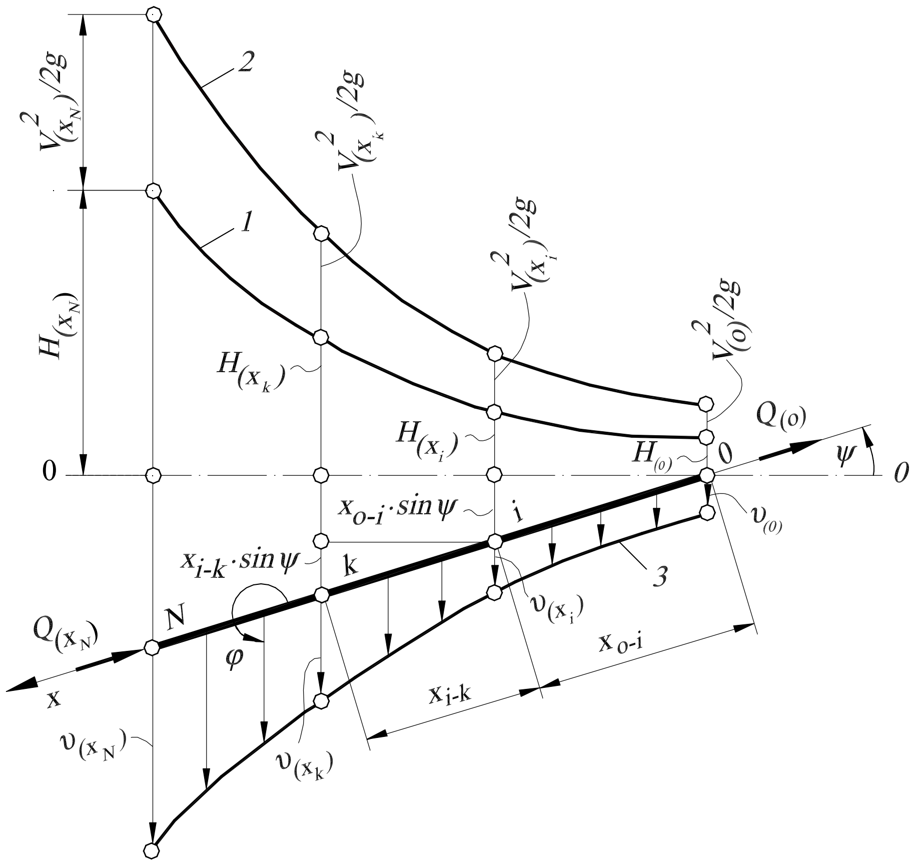

Fig.1. Schematic diagram of PDP calculation against the stream; 1 – curve of piezometric head; 2 – curve of total head; 3 – profile of average velocity of running out jets; x – axis of PDP

for $Re_{(x_i)} \dfrac{\Delta_{(x_i)}}{D_{(x_i)}} < 10$ ("smooth-pipe" turbulent flow):

$$\lambda_{(x_i)} = \frac{0.3164}{Re^{0.25}_{(x_i)}}; \tag{5}$$

for $10 \le Re_{(x_i)} \dfrac{\Delta_{(x_i)}}{D_{(x_i)}} \le 500$ (transitional turbulent flow):

$$\lambda_{(x_i)} = 0.11\left[\frac{\Delta_{(x_i)}}{D_{(x_i)}} + \frac{68}{Re_{(x_i)}}\right]^{0.25}; \tag{6}$$

for $Re_{(x_i)} \dfrac{\Delta_{(x_i)}}{D_{(x_i)}} > 500$ ("rough-pipe" turbulent flow):

$$\lambda_{(x_i)} = 0.11\left(\frac{\Delta_{(x_i)}}{D_{(x_i)}}\right)^{0.25}; \tag{7}$$

and the value of Reynolds' number for the main stream in PDP is determined according to the formula

$$Re_{(x_i)} = \frac{Q_{(x_i)} D_{(x_i)}}{\omega_{(x_i)} \nu_{(x_i)}}; \tag{8}$$

where $\nu_{(x_i)}$ is the kinematic viscosity; $v_{(x_i)}$ is the velocity of jet; φ is the coefficient of velocity; $\varphi_{(x_i)}$ and $\psi_{(x_i)}$ are the angles, the reference is made counterclockwise as it shown in Fig.1.

Coefficients of flow rate outlet-hole or of outlet-nozzle $\mu_{(x_i)} = f(\mathrm{Re}_{hole_{(x_i)}}, l/d)$ where l is the thickness of PDP wall or the length of outlet nozzle; d is the diameter of outlet-hole or of outlet nozzle; $\mathrm{Re}_{hole_{(x_i)}}$ is the Reynolds' number for the jet which flows through outlet-hole or through outlet-nozzle in the cross-section x_i of PDP, $\mathrm{Re}_{holer_{(x_i)}} = f(H_{(x_i)})$. For example, for a cylindrical outlet-nozzle at $Fr_{(x_i)}$>10, $We_{(x_i)}$>200, for perfect total compression and sharp inlet edges the value of the coefficient $\mu_{(x_i)}$ can be calculated by means of empiric formulae obtained by formulae from [5, pages 68-71]. One of these relations for the ratios: $l/d = 1\ldots1.5$, $\mathrm{Re}_{theor_{(x_i)}} = 10^3 ... 10^5$ or $l/d = 2\ldots5$, $\mathrm{Re}_{theor_{(x_i)}} = 50...15 \cdot 10^4$ or $l/d = 10\ldots50$, $\mathrm{Re}_{theor_{(x_i)}} = 80...15 \cdot 10^4$ is of the form [5, page 69];

$$\mu_{(x_i)} = \frac{1}{1.23 + \dfrac{58 \cdot l}{\mathrm{Re}_{theor_{(x_i)}} d}}; \tag{9}$$

where $\mathrm{Re}_{theor_{(x_i)}} = \sqrt{2gH_{(x_i)}} \cdot d / \nu$ is the Reynolds' number for a jet at a "theoretical velocity of running out" [5, page 61].

At the estuary of the PDP in the cross-section $x = 0$ (Fig. 1) the flow rate equals the transitive one $Q_{(0)} = Q_{tr}$, and the operating head $H_{(x)} = H_{(0)}$. The latter is calculated by the formula $q_{(0)} = \mu\omega_o\sqrt{2gH_{(0)}}$; the value of the flow rate $q_{(0)}$ through the last outlet-hole which is to be realized should be substituted into this formula.

3. AIM OF THE PAPER

To experimental test the technique of calculation for PDP developed by Chernyuk,V.V. [3] on the basis of the new approach to solving DEVMFF for PDP are determined according to Formula (1)

4. EXPERIMENTAL PROCEDURE

The investigations were carried out on an experimental PDP whose diameter D = 8.21 mm, the water was supplied by gravitation [6]. The material of the pipes was stainless steel. The pipes were joined by flanges.

In the network of experimental PDP, holes with diameter of 3.2 mm were drilled along a generatrix; coaxially to them, water outlets whose lengths was 25 mm and the inner diameter d = 3.2 mm were welded to the wall. They were situated with the interval multiple of 10d. Depending on the purpose, these outlets were used for dispensation along the path or they served as unions to which rubber pulse tubes where connected to join with piezometers (Fig. 2). For convince in reading the schematic diagrams, unions in the diagram (Fig. 2) a directed upward, and water outlets are oriented downward, as it really was. The inner diameter of rubber pulse tubes is 8 mm. Heads were measured by piezometers correct to 0.5 mm. The operating head in the experimental PDP was 3740 mm when the valve *11* at its end was closed (Fig. 2). Head tank *2* which has an overflow wall ensured constant head in the experimental PDP, constant flow rate; and it prevented pulsations.

The nozzle to pipe cross-section ratio of PDP was calculated according to the formula [7, page 30]:

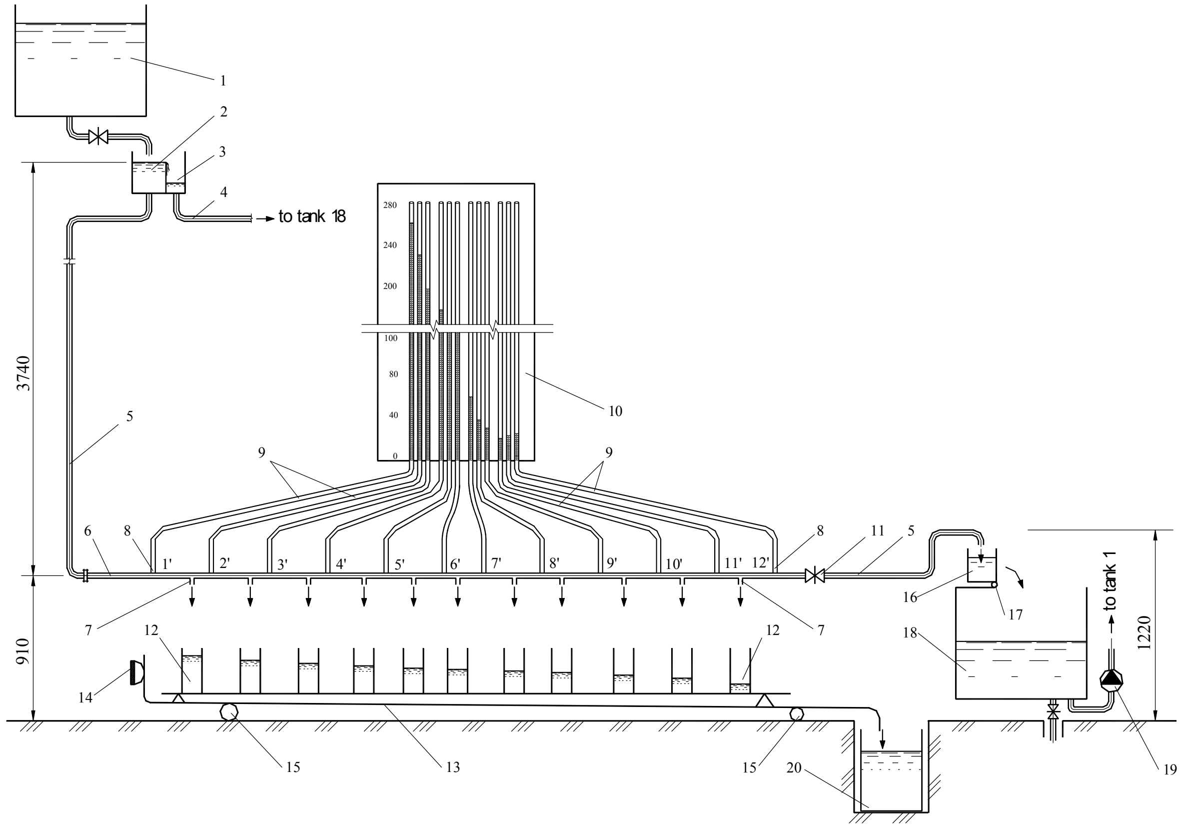

Fig. 2. Schematic diagram of experimental setup: 1 – tank; 2 – head tank; 3 – overflow tank; 4 – overflow pipe; 5 – supply pipe; 6 – experimental PDP; 7 – water outlets; 8 – unions; 9 – rubber pulse tubes; 10 – board of piezometers; 11 – valve; 12 – measuring vessels; 13 – movable trough; 14 – handle; 15 – rolling bearings; 16 – measuring tank; 17 – hinge; 18 – receiving tank; 19 – pump; 20 – water collecting tank; 1`–12` – numeration of unions (dimensions are given in mm)

$$f = \frac{n \cdot \omega}{\Omega}\ , \tag{8}$$

where ω is the area of the cross-section of water inlet nozzle, $\omega = \frac{\pi d^2}{4}$; n is the number of water inlet nozzles in the whole PDP; Ω is the area of the cross-section of the experimental PDP, $\Omega = \frac{\pi D^2}{4}$.

The non-homogeneity of the water dispensation along the path from the PDP is calculated like this [7, page 32]:

$$\eta = \frac{q_{beginning}}{q_{end}}\ , \tag{9}$$

where $q_{beginning}$, q_{end} are flow rates through the first and the last water inlet nozzles of PDP respectively.

The flow rates q of water through the nozzles where determined in terms of volume with a help of the measuring vessels *12* (Fig.2).

The relative change of non-homogeneity in the dispensation of water along the path is caused by the inclination of PDP compared to its zero inclination under other analogical conditions is

$$\frac{\Delta\eta}{\eta} = 1 - \frac{\eta_\psi}{\eta_o} \cdot 100\% \ , \tag{10}$$

where subscripts ψ and 0 denote the water flow in PDP with inclination to horizon at the angle of $\psi \neq 0$ and $\psi = 0$ respectively.

The flow rate at the end of PDP (Fig. 1)

$$Q_{\text{beginning}} = Q_{(xN)} = \Sigma q + Q_{tr} \ , \tag{11}$$

where Q_{tr} is the transitional flow rate at the end of PDP which was also determined in terms of volume with a help of the measuring tank *16* (Fig.2) according to Fig. 1, $Q_{tr} = Q_{(o)}$.

5. COMPARISON OF PDP CALCULATION TECHNIQUE [3] WITH EXPERIMENTAL DATA

PDP of intermediate lengths were investigated with eleven (Fig. 3a) and with eight (Fig.3b) water inlet nozzles whose nozzle to pipe cross-section ratio $f = 1.469$ and 1.215 and whose operating length $L = 2644$ mm and 1276 mm respectively.

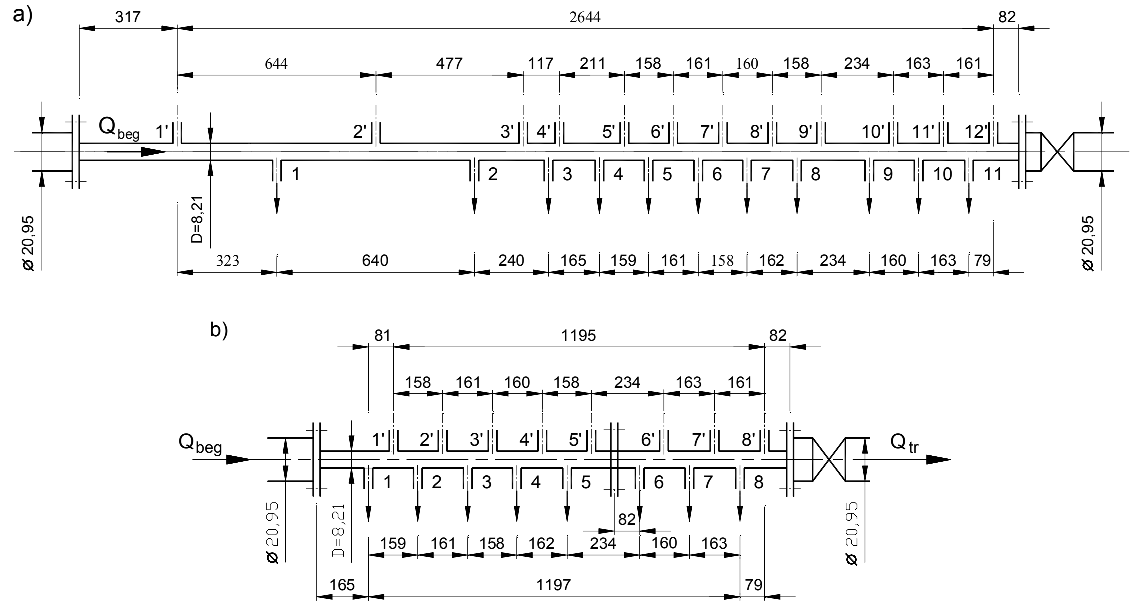

Fig. 3. Schematic diagram of experimental PDP whose $f = 1.469$ (a) and 1.215 (b): 1-11 – water inlet nozzles; 1`–12` – unions for connecting rubber pulse tubes; $Q_{\text{beginning}}$ – flow rate at beginning of PDP; Q_{tr} – transitional flow rate (dimensions are given in mm)

During investigation on PDP with $f = 1.469$, the transitional flow rate in the cross-section 0 (Fig. 1) was absence, and the head $H_{(0)} = 0.104$ m. With this, the non-homogeneity of the water dispensation along the path from PDP was $\eta = 2.77$ (Fig. 4).

The investigation on PDP with $f = 1.469$ (Fig. 6) were carried out under its different inclinations according to the schematic diagram given in Fig.5, at the absence ($Q_{tr} \neq 0$) and presence ($Q_{tr} = Q_{(o)} = 0$) of transitional flow rate in the cross-section 0 (Fig. 1).

According to Fig. 6, the non-homogeneity η of water dispensation along the path from PDP is shown in Table 1.

Table 1. Non-homogeneity of water dispensation from PDP along the path

Angle of inclination to horizon	$Q_{tr} \neq 0$		$Q_{tr} = 0$	
$\psi_{(x)}$, agree	η	$\Delta\eta/\eta$, %	η	$\Delta\eta/\eta$, %
0	1.671	—	1.867	—
5.3	1.945	–16.4	2.291	–22.7
354.7	1.622	2.9	1.692	9.4

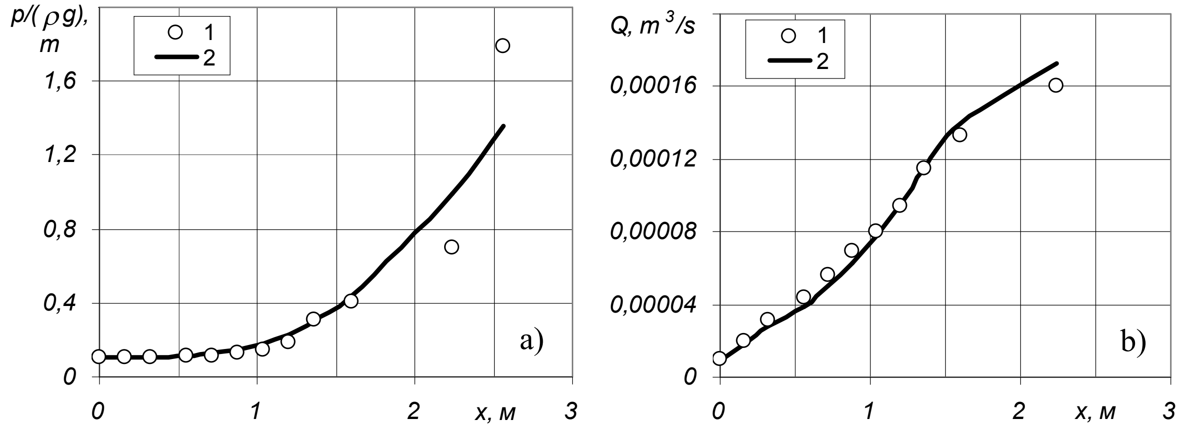

Fig. 4. Comparison of results for PDP whose *f = 1.469*:
a – piezometric head inside PDP; b – flow rate inside PDP;
1 – experimental data; 2 – calculation according to the formulae (2)–(7);
x-axis is directed against the stream [9]

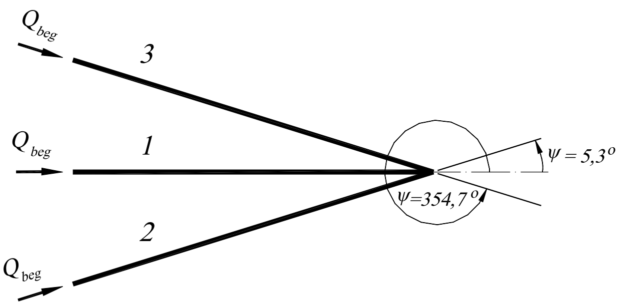

Fig. 5. Schematic diagram of inclined PDP:
1 – zero inclination ($\psi = 0^o$); 2 – descending of pipe along the flow ($\psi = 5.3^o$); 3 – ascending of pipe along the flow ($\psi = 354.7^o$)

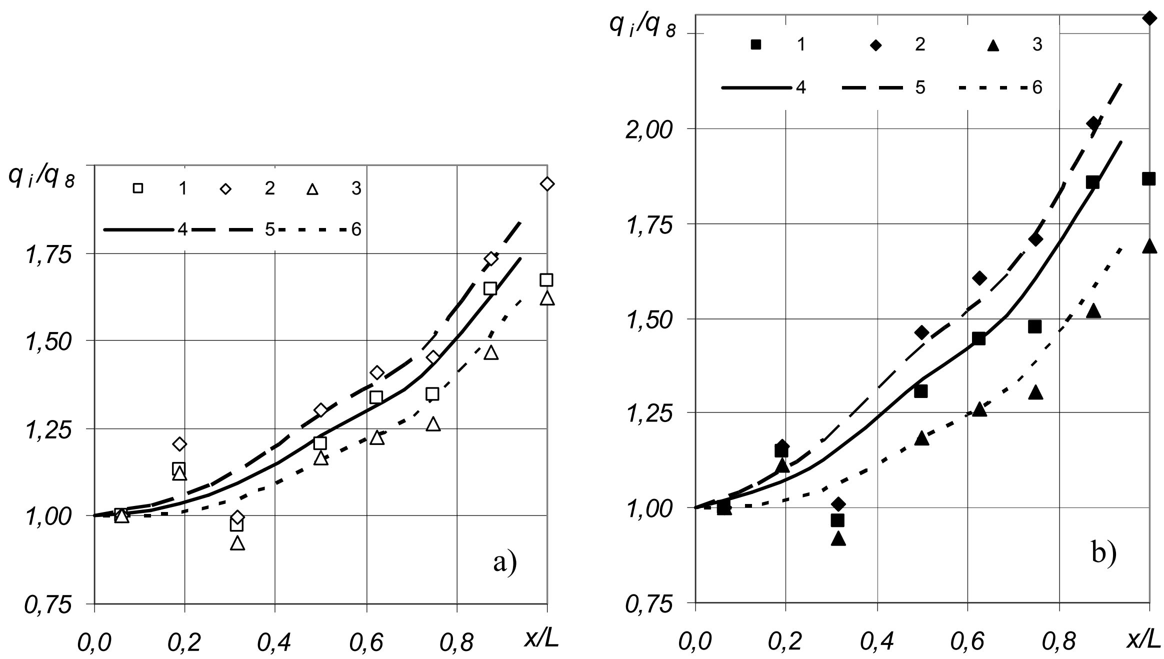

Fig. 6. Relative variation of water dispensation along the stream for PDP with f = 1.215 for $Q_{tr} = Q_{(o)} = 0$ (a) and $Q_{tr} \neq 0$ (b): 1-3 – experimental data; 4-6 – calculation according to the formulae (2)–(7); 1, 4 – $\psi = 0^o$; 2, 5 – $\psi = 5.3^o$; 3, 6 – $\psi = 354.7^o$;
L – operating length of PDP; x-axis is directed against the stream

Thus, the least non-homogeneity of water dispensation from PDP along the path is observed under ascending of pipe along the flow ($\psi = 354.7^o$), and the greatest one under descending of pipe along the flow ($\psi = 5.3^o$). The presence of transitional flow rate ($Q_{tr} \neq 0$) lessens the non-homogeneity of water dispensation from PDP along the path. This can be seen from our calculation and is confirmed by experiments (Fig. 6, Table 1).

6. CONCLUSIONS

The method of calculation for pressure distributive pipelines (PDP) [3] is good for calculations horizontal, ascending, and descending of PDP; this is confirmed by experiments. The values of heads, of flow rates of water inside PDP and of the water dispensation along the path which are calculated according to the formulae (2)–(7) practically coincide with the experimental data.

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