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Influence of Values of Angle of Jet-joining on Non-uniformity of Water Inflow Along the Path in Pressure Collector-Pipeline

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Abstract. Results of experimental investigation of the influence of values of the angle β at which jets join a pressure pipeline on the non-uniformity of water inflow along the collector-pipeline (CP) are presented. The inner diameter D of the CP is 11.28 mm, and the diameter d of the nozzles is 4.83 mm, $d / D = 0.428$. Five CPs in which all the nozzles had been installed at angles β, the latter was given the values of: 0^o; 45^o; 90^o; 135^o; 180^o, where investiguated. A CP in which in the initial segment the nozzles had been installed at the angle $\beta = 0^o$, and in the middle and terminal segment $\beta = 180^o$ has been also investigated. The greatest non-uniformity of the water inflow along the CP was obtained for CPs with $\beta = 90^o$, and the least one for CPs with diffrent values of the angle β. The obtained results give us the reason to conclude that it is possible to adjust the non-uniformity of water inflow into a CP by means of the method of selection of different values of angle β at which the jets join the CP.

Key words: pressure collector-pipeline; angle of jet-joining; non-uniformity of water inflow along the path.

Conference topic: Water engineering.

Introduction

Pressure collector-pipeline (CPs) are used in different technologitical processes, for example in heat supply (solar collectors), ventilation (exhaust system), water-supply (pipe water-intakes), water-removal (conduits of purification structures), etc. Accurate hydraulical calculation of such pipeline can be made only with the help of hydraulics of variable mass (Navoyan 1975). In practice, in the majority of cases, it is expedient to ensure uniform water-inflow along the CP. Different methods of reduction of uniformity of inflow to pressure CP were investigated (Voloshchuk 2001; Kravchuk 2004). However, in all known works, there were considered only CPs with ortogonal joining of jets. The technigue of calculation of pressure CPs based on solving generalized differential equation of variable flow rate (Yakhno *et al.* 2016: 312–364) is suggested by prof. V. Cherniuk. This technigue tnsures calculation of CPs with different values of the angle β.

Aim of the work: to verify the presence of the influence of values of the jet-joining angle β on non-uniformity of water inflow into pressure collector-pipeline along the path.

Experimental set-up

In order to acheive our aim, the experimental set-up (Fig. 1) (Cherniuk, Ivaniv 2015) has been designed and manufactured. The length of the experimental pipeline was 2770 mm, including its perforated part 1680 mm long, on which 11 nozzles were installed. The distances between all input nozzles were the same and equal to 160 mm. A CP of the inner diametr D equal to 11.28 mm has been investigation. The inner diametr d were equal to 4.83 mm. The diameter of the lateral hole of the nozzle is equal to the inner diameter of the nozzle (Fig. 2). The ratio of the diametrs d / D was equal to 0.428. The nozzels were installed in the wall of CP so that it was possible to incline them relative to their longitudel axis (Fig. 3). This ensured adjustment of values of jet-joining angles β to the direction of main stream in the CP from 0^o to 360^o. Five CPs in which all nozzles had been installed at the same angle β have been investigation, β was given the values of 0^o; 45^o; 90^o; 135^o; 180^o. A CP in which five nozzles in its initial segment had been installed with $\beta = 0^o$, and the other 6 nozzles (in the midle and the terminal segments) with $\beta = 180^o$ has been also investigation. The experimental pipline had been instaled horizontally.

The experimental pipline has been installed in a transporant germetic cylinder (Fig. 1, Fig. 3). The axis of the experimental pipline is situated at the level of 3,5 m below the level of water in the head tank, from which water was supplied into the transparent cylinder. During the experiments, the water head H_{out} (Fig. 4) outside the experimental pipline varied from 0.3 to 2.5 m. The temperature of the water in CP during the experiments was within the rauge of 18.0–21.0 ^oC.

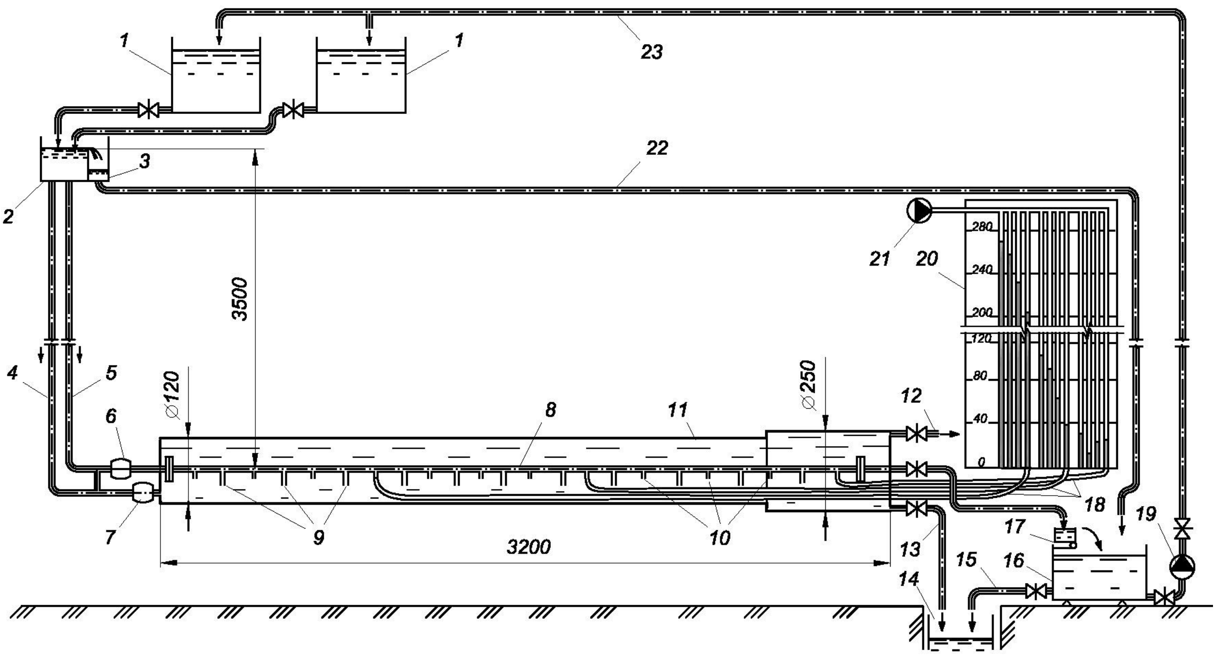

Fig. 1. Schematic diagram of experimental set-up: 1 – capacity for water ; 2 – head tank with overflow wall; 3 – discharge tank; 4, 5 – supplying pipes; 6, 7 – water meters; 8 – experimental pipeline; 9 – input nozzles; 10 – pipe connections for connections of pulls line from piezometers; 11 – transparent cylinder; 12 – outlet pipe for air release; 13 – discharge pipe; 14 – water collecting channel; 15 – discharge pipe; 16 – receiving tank; 17 – meter-tank; 18 – pulls line; 19 – circulation pump; 20 – piezometric shield; 21 – compressor; 22 – discharge pipeline; 23 – reverse pipeline (the pulls lines from the connections 1–3; 5–7; 9–11 are not conventionally shown) (Cherniuk, Ivaniv 2017)

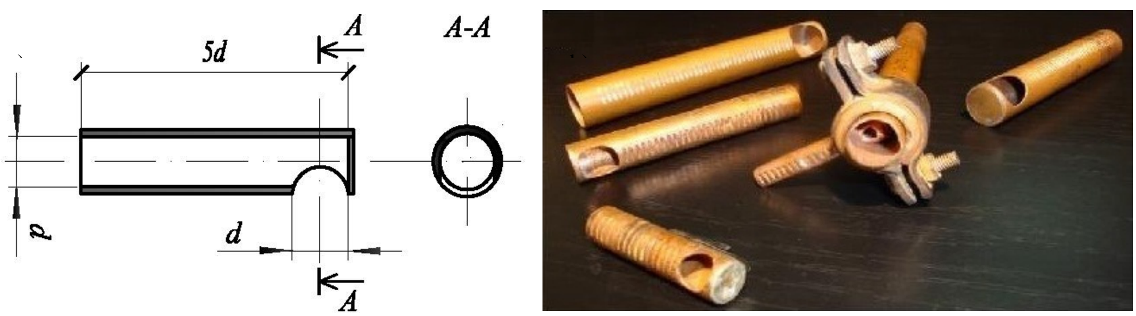

Fig. 2.

Input cylindrical nozzles with orthogonal lateral outlet: a – diagram of nozzles; b – nozzle of different d (at the center a nozzle of d = 4.83 mm, installed in a CP of D = 11.24 mm is shown) (Cherniuk, Ivaniv 2017)

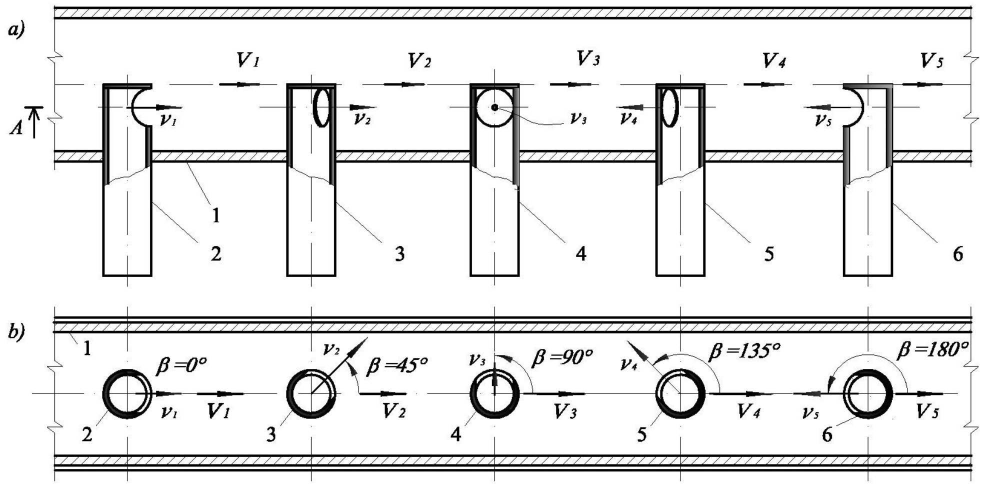

Fig. 3. Diagram of installation of nozzles with different angles β of jet-joining in a collector-pipeline: a – axial section of CP; b – section 1-1; 1 – wall of CP, 2 – nozzle with the angle of $\beta = 0^o$; 3 – ditto for $\beta = 45^o$; 4 – ditto for $\beta = 90^o$; 5 – ditto for $\beta = 135^o$; 6 – ditto for $\beta = 180^o$; V_1, V_2, V_3, V_4, V_5 – velocities of stream in CP; v_1, v_2, v_3, v_4, v_5 – velocities of jets at outlets of nozzles (Cherniuk, Ivaniv 2017)

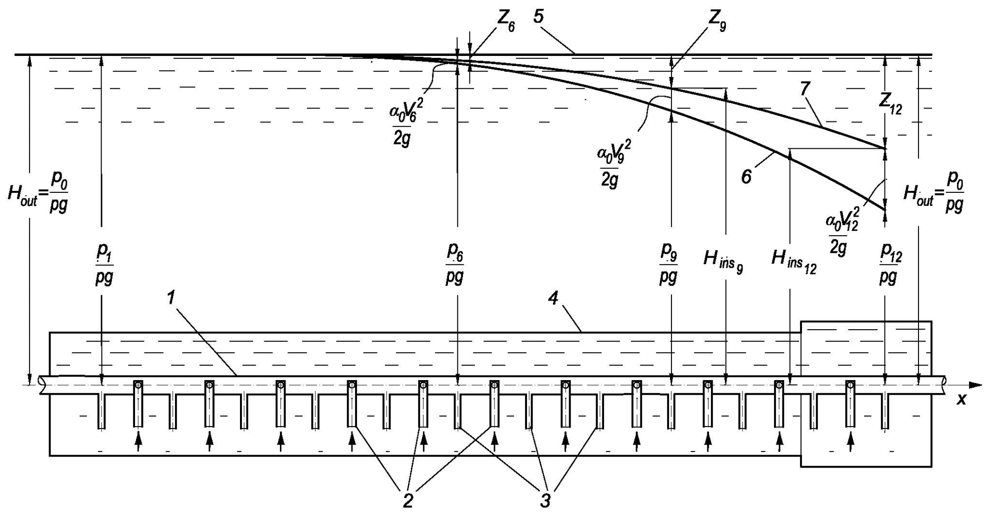

Fig. 4. Schematic diagram for calculation of full operating head in CP: 1 – CP investigated; 2 – input nozzles; 3 – connection pipes for connection of pulls lines from piezometers; 4 – transparent cylinder for CP; 5 – water level which corresponds to the head in the transparent cylinder; 6 – piezometric line for water stream inside CP; 7 – ditto, line of full operating head; x – axis of CP (Cherniuk, Ivaniv 2017)

Mathematical processing of experimental data

The full operating head at i^{th} (referenced from beginning of CP) input nozzle, under the action of which water jets went into CP, (see Fig. 4) were calculated according to the formula:

$$Z_i = H_{out} - \frac{p_i}{\rho g} - \frac{\alpha_0 V_i^2}{2g}, \qquad (1)$$

where: H_{out} is the actual head outside the collector-pipeline; $p_i/\rho g$ is the piezometric head at the i^{th} nozzle; $\alpha_0 V_i^2/2g$ – is the kinetic-energy head in the CP in from of the i^{th} nozzle.

The water inflow into CP through the i^{th} nozzle was calculated theoretically depending on the full operating head Z_i at it:

$$q_i = \mu_i \omega \cdot \sqrt{2gZ_i}, \tag{2}$$

where, μ_i is the coefficient of flow rate, the value of $\mu = f(Re_d)$ for the investigated nozzles we have determined experimentally (Ivaniv, Cherniuk 2016); ω is the area of the cross-section of the nozzle; g is gravity acceleration; Z_i is the operating head at the nozzle (see (1)).

The flow rate of water in CP at k^{th} nozzle, according to the expressions (1) and (2), we were calculated according to the formula:

$$q_k = \sum_{i=1}^{k} q_i + \mu_k \omega \cdot \sqrt{\left[2gH_{out} - \frac{2p_k}{\rho} - \alpha_0 \left(\frac{1}{\Omega_k} \sum_{i=1}^{k-1} q_i\right)^2\right]}, \tag{3}$$

where, $\sum_{i=1}^{k} q_i$ is the flow rate in CP in front the k^{th} nozzle; μ_k is the coefficient of flow rate of the k^{th} input nozzle; ω is the area of the cross-section of the area of the nozzle; H_{out} – is the actual head of water outside the CP; $p_k/\rho g$ is the piezometric head at the k^{th} nozzle; a_0 is the Coriolis coefficient, $a_0 = 1.05$; Ω is the area of cross-section of the CP.

The non-uniformity of distribution of heads Z_i along CP (Smyslov, Ezerskiy 1980):

$$\eta_z = \frac{Z_m}{Z_{beg}}, \tag{4}$$

where, Z_m is the maximal Z_{max} or minimal Z_{min} head at nozzles; in our experiments Z_m is the head at the terminal nozzle, $Z_m = Z_{end} = Z_{11}$; Z_{beg} is the head at the first nozzle, $Z_{beg} = Z_1$.

The non-uniformity of the distribution of the water inflow q_i into the CP (Smyslov, Ezerskiy 1980):

$$\eta_q = \frac{q_m}{q_{beg}}, \tag{5}$$

where, q_m is the maximal q_{max} or minimal q_{min} inflow through one nozzle, $q_m = q_{end} = q_{11}$; q_{beg} is the inflow through the first nozzle, $q_{beg} = q_1$.

Results of experimental investigation

For the sake of comparison, the experimental data which have been obtained for CPs of different values of angle β of jet-joining for close value of Reynolds criteria ($\mathrm{Re_D}$ = 5211 … 6354) are presented together. The distribution of full operating heads along the five CPs with the input nozzles installed with the angles β of jet-joining equal to 0^o, 45^o, 90^o, 135^o and 180^o are presented in relative coordinates $z_i/z_{end} = f(x_i/l)$ in Fig. 5, *a*. The water inflows correspouding to these head through input nozzles are shown in the relativen coordinates $q_i/q_{end} = f(x_i/l)$ in Fig. 5, b. In each of the five CPs presented in Fig. 5, the values of the angle β was equal for all the eleven input nozzles.

It is detected that the least non-uniformity of distribution of full operating heads along CP is obtained at $\beta = 45^o$, and the greatest one at $\beta = 90^o$ (see Fig. 5, a, Table 1). At the same time, the least non-uniformity of water inflow along the path is obtained for CP with $\beta = 45^o$, and the greatest one at $\beta = 180^o$. The non-coincidence of the greatest non-uniformities of distribution of heads to that of inflow is caused by the values of coefficient μ of flow rate of nozzles which were in the formula (2) for calculation flow capacity of the nozzles. At $\beta = 90^o$ and at equal values of Re, the coefficient μ flow rate is greater than that for $\beta = 180^o$ (Table 2).

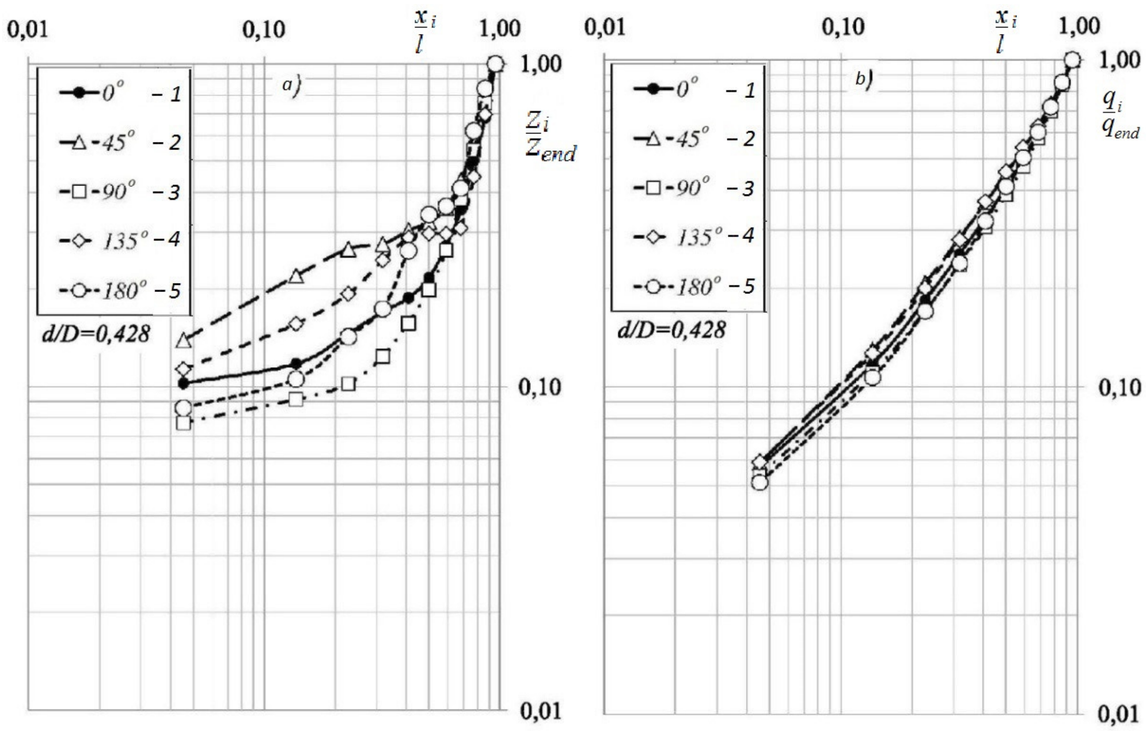

Fig 5. Distribution of operating heads along CP (a) and distribution of water inflow into CP through individual input nozzles along the path (b) for CP whose angles β and Reynolds criteria are corresponded equal to the following: $\beta = 0^o$, Re_D = 6320 – (1); $\beta = 45^o$, Re_D = 5211 – (2); 90^o – Re_D = 6354 – (3); 135^o – Re_D = 5499 – (4); 180^o – Re_D = 5931 – (5) (Cherniuk, Ivaniv 2017)

Table 1. Non-uniformity of distribution of operating heade in CP η_z and that of fluid inflow η_q into CP (Cherniuk, Ivaniv 2017)

Angle β	Operation heads at nozzles, mm		$\eta_z = \frac{Z_{max}}{Z_{beg}}$	Inflow at nozzles, cm^3/s		$\eta_q = \frac{q_{max}}{q_{beg}}$	Reynolds criterion, Re_D
	Z_{beg}	Z_{max}		q_{beg}	q_{max}		
0^o	3.0	29.32	9.78	3.04	53.17	17.52	6320
45^o	2.5	17.96	7.19	2.87	48.93	17.05	5211
90^o	2.5	32.38	12.95	2.98	55.47	18.63	6354
135^o	2.5	22.08	8.83	3.05	52.63	17.25	5499
180^o	2.0	23.33	11.67	2.73	53.42	19.57	5931

Notes: The Table is formed on the basis of data from the graphs presented in Fig. 5.

Table 2. Values of coefficient of flow rate of nozzles depending on angle β (Cherniuk, Ivaniv 2017)

Angle β	0^o	45^o	90^o	135^o	180^o
coefficient of flow rate μ	0.705–0.616	0.707–0.622	0.734–0.611	0.752–0.627	0.753–0.629
Reynolds criterion, Re_d	941–4157	978–3245	1052–4416	978–3528	897–3726

Notes: 1. The coefficient μ of the flow rate is presented for the ratio $d/D = 0.428$; 2. Less values of the coefficient μ concern greater values of Reynolds criterion, Re_d; 3. The value of the coefficient μ of flow rate has been obtained experimentally [6].

For a combened collector-pipeline in which five nozzles in begining segment were installed at the angle of $\beta = 0^o$, and the other six nozzles at $\beta = 180^o$, less non-uniformities of distribution of optrating heads η_z along CP are obtained (Fig. 6, *a*) and of the water inflow η_q along the path (Fig. 6, *b*) are obtained than those for CP with $\beta = 0^o$ for all the eleven nozzles and for CP with $\beta = 180^o$. The numerical values of non-uniformity η_z and η_q are given in Table 3.

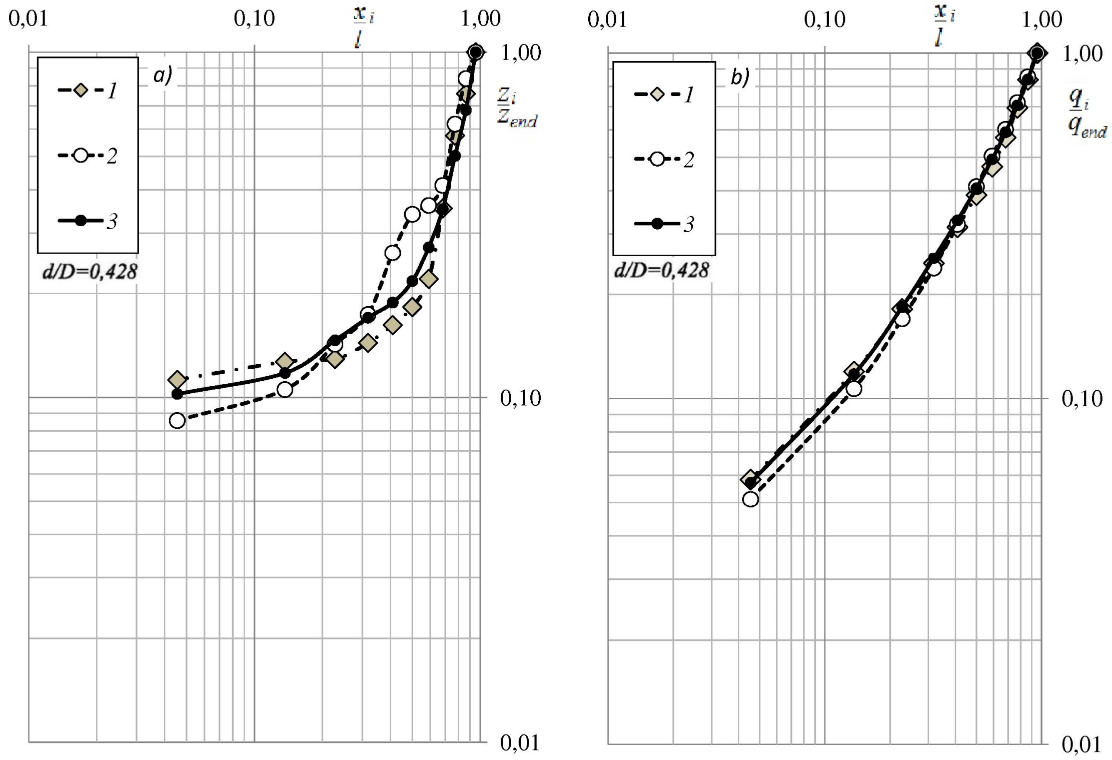

Fig 6. Distribution of operating heads (a) in different CPs and that of water inflow in them (b): 1 – combined CP for which the first five nozzles are with $\beta = 0^o$, and the other six nozzles with $\beta = 180^o$ for Re_D = 7242; 2 – CP with $\beta = 180^o$, Re_D = 5831; 3 – CP with $\beta = 0^o$, Re_D = 5827 (Cherniuk, Ivaniv 2017)

Table 3. Non-uniformity of distribution of operating heade η_z in CP and that of fluid inflow η_q into CP (Cherniuk, Ivaniv 2017)

Angle β	Operation heads at nozzles, mm		$\eta_z = \frac{Z_{max}}{Z_{beg}}$	Inflow at nozzles, cm^3/s		$\eta_q = \frac{q_{max}}{q_{beg}}$	Reynolds criterion, Re_D
	Z_{beg}	Z_{max}		q_{beg}	q_{max}		
0^o	3,0	29,32	9,78	3,04	53,17	17,52	7242
180^o	2,0	23,33	11,67	2,73	53,42	19,57	5831
0^o and 180^o (combined CP)	7,0	62,33	8,90	4,48	79,91	17,16	5827

Notes: The Table is formed on the basis of data from the graphs presented in Fig. 6.

There have been also investigation a CP with $D = 20.18\,mm$ and $d = 8.02\,mm$ with the same values of angles β of jet-joining ($0^o;\ 45^o;\ 90^o; 135^o;\ 180^o$). For this CP, the less non-uniformity of inflow was achieved at the angle of $\beta = 0^o$, and the greater one at $\beta = 90^o$. In the same way, for a combined CP (five of the first nozzles installed at the angle of $\beta = 0^o$, and the other oues at $\beta = 180^o$). Similar results have been obtained for a CP with $D = 20.18\,mm$ and $d = 6.01\,mm$. For this CP, the less non-uniformity η_q is achieved at $\beta = 0^o$, and the greater at $\beta = 135^o$, and the least one for a combined CP.

Conclusions

Resulte of investigation of five collector-pipelines with $D = 11.28\,mm$ and with diameters of the input nozzles of $d = 4.83mm$, which were installed at equal angles β, correspondingly, 0^o, 45^o, 90^o, 135^o; 180^o are presented in this work. There is also investigated a combined CP with the same values of D and d in which in its begining segment the nozzles were installed at the angle of $\beta = 0^o$, and in the rest length at $\beta = 180^o$. The greatest non-uniformity of the water inflow along the path is obtained for CPs with $\beta = 90^o$, and the least one for the combined CP (with diffrent values of the angle β). We assert that the non-uniformity of water inflow along the path into a CP can be adjusted by means of the method of selection of different values of jet-joining angle β along CP.

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