8.2 Control of flow rate ratio in pipelines by introducing drag-reducing polymers into stream

Introduction.

In the development and construction of peaceful purpose commercial devices, which employ moving liquids, special progress is achieved, in particular, in pumping-over liquids [386].

The introduction of energy saving technologies, equipment, and materials is a trend of energy-efficiency measures complex in building industry [387].

Analysis.

The effect of decrease in hydraulic resistance of turbulent streams by drag-reducing polymers (DRP's) whose molecules are of a chain form is called Toms' phenomenon. In this situation, the presence of local drags in a pipeline causes decrease or increase in their hydraulic resistance; whether the resistance decreases or increases, it depends on geometry of local drags, concentration of DRP's, and Reynolds' number [388].

The physical properties of DRP's to cause head losses both of positive and negative signs in local drags of pipelines was used in developing different resource and energy saving means for the control of expenditures of fluid [389] (Fig.1). The device offered can be used as a proportioning pump or a mixer for several liquids in the proportion we need.

This method includes distribution of a stream into pipelines and the control of the proportions of flow rate in them. Before a ramification of a pipeline, DRP's is introduced into the stream, and control is carried out by means of a block consisting of two or more parallel pipe-shaped channels of constant or variable cross-sections,

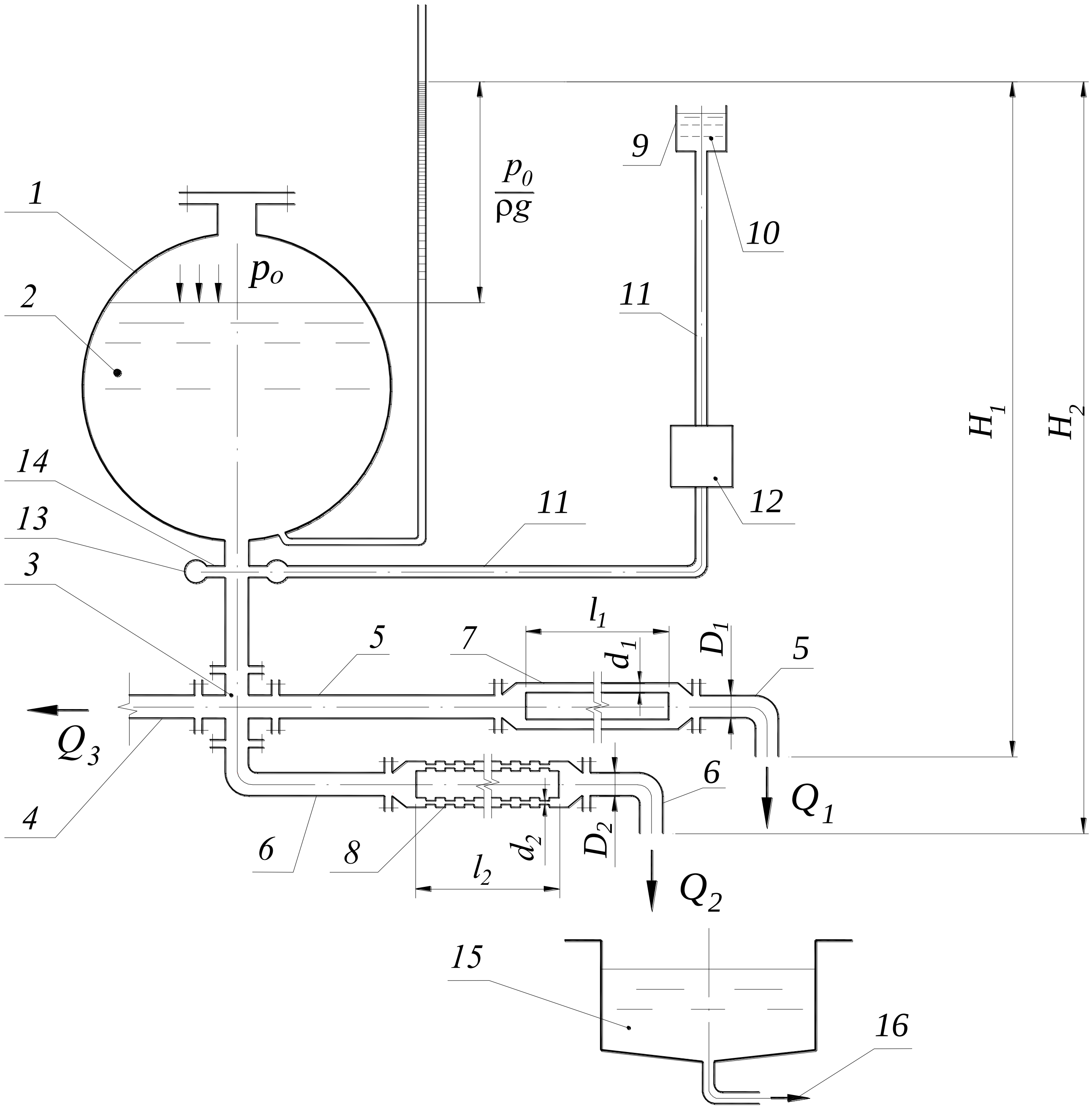

Figure 1. Flow governor for liquids in pipeline:

1 – reservoir; 2 – liquid; 3 – distributing collector; 4-6 – pipelines;

7 – block of constant cross-section pipes; 8 – block of variable cross-section pipes;

9 – tank; 10 – DRP's; 11 – supply pipe; 12 – proportioning device;

13 – torus-shaped chamber; 14 – connecting pipes; 15 – receiving tank (settling tank);

16 – DRP's for repeated use

hydraulic characteristics of which are previously known. Because the resistance of a block of parallel channels makes the main part of the general resistance of the pipeline branch on which it is located, this gives us a possibility to carry out distribution both to increasing and decreasing of the flow rate; external sources of energy being non-used. When introducing DRP's, hydraulic resistance of constant cross-section pipes decreases, and hydraulic resistance of variable cross-section pipes increases. To every concentration of DRP's corresponds a certain ratio of flow rates in different branches, and this gives us a possibility to form this ratio in non-discrete (continuous) way.

Research Goal.

The aim of this paper is to substantiate the use of the method suggested by us. For this purpose, let us analyse the ratios of flow rates of liquid in pipelines when DRP's is introduced into the stream.

Results.

When DRP's is introduced, a regulatory characteristic of flow rates of liquid in a pipeline becomes [390]:

$$\frac{Q_s}{Q_w} = \frac{\mu_s}{\mu_w} \approx \sqrt{\frac{\zeta_w + \alpha_w}{\zeta_s + \alpha_s}}, \qquad (1)$$

where μ is the discharge coefficient; ζ is the coefficient of hydraulic resistance of a block of parallel channels; α is the energy-average factor; indices "s" and "w" denote the streams of water solution of DRP's and pure water respectively.

When $\alpha_s \approx \alpha_w$ and $\zeta = \zeta_{contr} + \zeta_{non-contr}$, where the indices "contr" and "non-contr" correspond to controlled and non-controlled segments of the pipeline, formula (1) can be rewritten in the form [390]:

$$\frac{Q_s}{Q_w} \approx \frac{1}{\sqrt{1 - \zeta_* \cdot \frac{\Delta\zeta}{\zeta}}}, \qquad (2)$$

where $\frac{\Delta\zeta}{\zeta} = 1 - \left(\frac{\zeta_s}{\zeta_w}\right)_{contr}$, and the simplex $\frac{\zeta_s}{\zeta_w}$ characterizes the effectiveness of DRP's; ζ_* is the coefficient of control that determines the depth of control

$$\zeta_* = \frac{\zeta_{w_{contr}}}{\zeta_{w_{contr}} + \zeta_{w_{non-contr}} + \alpha_w}, \quad (3)$$

or, under the condition of the control when $\zeta_{contr} >> \zeta_{non\text{-}contr}$,

$$\zeta_* \approx \frac{1}{1 + \dfrac{\alpha_w}{\zeta_{w_{contr}}}}. \quad (4)$$

Let us consider the use of DRP's.

It is proved that the flow rate control by introducing fresh made [390] and destructed [391] water solutions of DRP's are possible. In the latter case we can write [391]:

$$\left(\frac{\Delta\zeta}{\zeta}\right)_n = \left(\frac{\Delta\zeta}{\zeta}\right)_o \cdot \exp(-a_1 \cdot n), \quad (5)$$

where a_1 is an empirical coefficient; n is quantity of passes through the pipeline; indices "o" and "n" denote fresh made and destructed water solutions of DRP's respectively.

When we use variable cross-section pipes of the form of round sudden axisymmetrical expansions and contractions, for fresh made water solutions of DRP's (index "o" is omitted) the relation $\frac{\Delta\zeta}{\zeta} = f(C)$, where C is the concentration of DRP's in the fluid flow, when $C \le C_{opt}$ is [390]:

$$\frac{\Delta\zeta}{\zeta} = \frac{C}{a_2 + b_2 \cdot C}, \quad (6)$$

where a_2 and b_2 are semi-empirical coefficients.

For round sudden axisymmetrical expansions of the pipes, for any constant value of DRP's concentration in the fluid flow (below $C \le C_{opt}$) the relation $\frac{\Delta\zeta}{\zeta} = f(n)$, where n is the expansion ratio that is described by the function [392]:

$$\frac{\Delta\zeta}{\zeta} = \frac{a_3 + b_3 \cdot n}{1 + c_3 \cdot n + d_3 \cdot n^2}, \tag{7}$$

where a_3, b_3, c_3 are empirical coefficients. Besides, it is expedient to use DRP's when $n \le (12.6 \pm 0.9)$ [392].

For round sudden axisymmetrical contractions of the pipes studied at $m \le 0.3$ and $C \le C_{opt}$ the values of $\frac{\Delta\zeta}{\zeta}$ are independent of the contraction ratio m [388, c. 8].

Let us show the effectiveness of the control of flow rate ratios by method that we have suggested.

Because it is the discharge coefficient μ that is the main parameter characterising the flow rate of a liquid, we determine it by the formula

$$\mu = \frac{Q}{\omega \cdot \sqrt{2gH}} \tag{8}$$

according to the examples given in [394].

The computations are given in Table 1. The uses of DRP's in constant cross-section pipe the discharge coefficient are decreased. The uses of DRP's in periodic cross-section pipe with abrupt contractions and abrupt expansions the discharge coefficient are increased.

At the same time change the flow rate of liquid in the case of introduction of DRP's (Table 2) we determine as the excess flow rate [395]

$$\Delta Q = Q_s - Q_w \tag{9}$$

and the increase in flow rate increment [396]

$$FI = 1 - \frac{Q_w}{Q_s}. \tag{10}$$

The introduction of energy-efficient technologies requires repeated use of the solutions of DRP's, their preparation and storing.

DRP's are produced by industry both in the form of gel and in powder. Repeated use of their solutions can be carried out in several ways. One of them, as is mentioned above, is the use of destructized water solutions of DRP's. Their concentration in a solution can be measured, for example, by means of device [397]. Another way is to use hydrophilic DRP's of variable solubility obtained by a condensation reaction of 1-2 percent water solution of polyacrylamide with formaldehyde [398]. This partially

Table 1: $\frac{\mu_s}{\mu_w}$-ratios

Block of parallel channels	DRP's	Concentration of DRP's C, kg/kg	Head H, m	Flow rate Q, sm^3/s	Discharge coefficient μ	$\frac{\mu_s}{\mu_w}$-ratio
Constant cross-section d_1 = 5.81 mm $l_1 = 140 \cdot d_1$	Water solution of polyacrylamide	0	1.0	55.2	0.4700	1.728
		0.0001	1.0	95.4	0.8120	
Periodic abrupt contractions and abrupt expansions d_2 = 0.80 mm $l_2 = 200 \cdot d_1$	Water solution of poly(ethylene oxide)	0	1.0	0.290	0.1300	0.142
		0.0001	1.0	0.041	0.0184	

Table 2: Change the flow rate

Block of parallel channels	Flow rate, sm^3/s	Excess flow rate ΔQ, sm^3/s	Increase in flow rate increment FI
Constant cross-section d_1 = 5.81 mm; $l_1 = 140 \cdot d_1$	Q_w = 55.2	40,2	0,421
	Q_s = 95.4		
Periodic abrupt contractions and abrupt expansions d_2 = 0.80 mm; $l_2 = 200 \cdot d_1$	Q_w = 0.290	-0,249	-6,07
	Q_s = 0.041		

sewed together DRP's that swell in water are introduced into the stream, they are being adsorbed by and adhere to the pipe wall, and they become covered with medium layer of small viscosity. Owning to the partial tearing off by the stream of outer layer of the obtained mosaic covering the carrying capacity of the pipeline changes. After allowing the DRP's to settle, it can be repeatedly used many times.

The problem of preparing, storing and preserving DRP's solutions is solved by the use of so called fast made solutions of DRP's [399]. Unlike the previously prepared solutions of DRP's, the time necessary to prepare fast made solutions of DRP's is 0.15 to 2.0 s; there is no extremum of the value of effectiveness resistance changes $\frac{\Delta\zeta}{\zeta}$ when the concentration of saturation occurs.

Conclusions. A new method of flow rates distribution of liquid among several pipelines is suggested, substantiated, and experimentally proved. This gives a possibility to control flow rates ratios of liquid in pipelines.