INVESTIGATION OF THE INFLUENCE OF POLYMER ADMIXTURES ON THE MAGNITUDE OF THE LOCAL DRAG COEFFICIENT

Yu. F. Ivanyuta and L. A. Chekalova UDC 532.543.6

Experimental data are presented on the influence of polyox-admixtures in an aqueous solution on the magnitude of the local drag coefficients. Theoretical and experimental results on determining the pressure drop in a pump during the flow of polymer solutions in a real hydraulic apparatus are compared.

1. Besides the normal sections of constant cross section, any real hydraulic system contains different kinds of connecting and transition sections, rectilinear and curvilinear, with constant or variable cross sections varying smoothly or suddenly, as well as diverse throttling or shut-off adapters.

The pressure losses in the shaped parts of a pipeline are determined mainly by the stream energy losses in vortex formation, caused by strong retardation of the stream, and its separation because of the presence of a positive pressure gradient (upon the sudden expansion of the stream in diffusors because of an abrupt change in the system cross section, etc.).

Just as friction, separation, vortex-formation, and their associated velocity redistributions cause a loss in mechanical energy. These phenomena are therefore an additional source of hydraulic drag so that the total hydraulic drag of the pipes is comprised of the friction drag and the drag due to separation (vortex formation). This latter drag is customarily called local since it always is caused by local changes in the pipeline configuration and is concentrated in a comparatively small section in contrast to the friction drag which is distributed uniformly over the whole length of the pipe.

In the case of flow of aqueous polymer solutions in hydraulic systems, many experimenters have remarked the influence of the polymer admixtures on the magnitude of the friction drag coefficient. This influence can be estimated quantitatively depending on the flow mode (Reynolds number), size of the pipelines, and kinds of polymers (for example, [1]). However, data about systematic investigations of the influence of polymer admixtures on the magnitude of the local drag coefficient are lacking. Some information about this question is contained in the papers of Pisolkar [2] and Lipatov [3]. To supplement the data in [2, 3], individual shaped parts of pipelines were tested in streams of water and polymer solutions in a hydraulic apparatus [1], and computations on determining the drag of the whole hydraulic system, including tanks, rectilinear pipeline sections, wedge gate valves, elbows with different angles of rotation, washers, were also verified experimentally.

The polyox WSR-301 and polyacrylamide were chosen as polymers and solutions in the concentrations $c = 10^{-3}$ g/cm^3, $c = 2 \cdot 10^{-3}$ g/cm^3 (polyox), and $c = 1.4 \cdot 10^{-5}$ g/cm^3 (polyacrylamide) were prepared therefrom.

2. To determine the influence of the polymer admixtures in a water stream on the local drag coefficient, the magnitudes of these coefficients were found in the water stream. Determined during the tests were:

1) the local drag coefficients of the shaped parts of the pipeline with a sudden stream expansion when going from pipelines of diameters $d_1 = 20.9$ and $d_1 = 9.75$ mm to a pipeline with the diameter $d_2 = 35.5$ mm and a sudden stream contraction and expansion in a $d = 70$ mm diameter pipeline because

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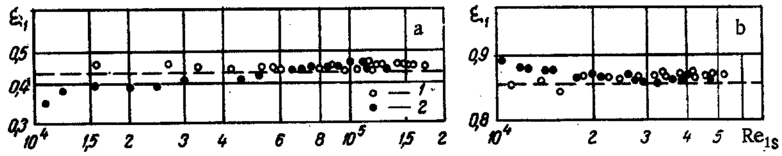

Fig. 1. Dependence of the local drag coefficient $\xi_1 = 2g\Delta h_{local}/v_1^2$ on the Reynolds number $Re_{1s} = v_1 d_1/\nu_s$ for water flows in a polyox solution in a pipe with a sharp change in the diameter from $d_1 = 20.9$ mm (a) and $d_1 = 9.75$ mm (b) to $d_2 = 35.5$ mm: 1) water; 2) polyox solution, $c = 10^{-3}$ g/cm^3; dashes are the computation [4], water.

of insertion of washers with diameters $d_0 = 26.5$, 41.5, and 54 mm and 45° taper angle in its channel;

2) the local drag coefficient of the flow in elbows with 90 and 180° stream rotation angles and a gate valve.

The shaped part of the pipeline being investigated was placed in a straight constant-diameter pipe which had a length not less than 25 d_1 both ahead of and after this part and permitted elimination of the influence of the component parts of the hydraulic apparatus on the local drag coefficient to be determined.

The pressure drop at some local section of the pipeline, enclosing the shaped part being tested, was measured in the tests. As a rule, the length of the local section was 4-10 d up and downstream of the location of this part.

The magnitude of the local drag coefficient was calculated by means of the formulas

$$\xi_1 = \frac{2g\Delta h_{local}}{v_1^2} \quad \text{or} \quad \xi_2 = \frac{2g\Delta h_{local}}{v_2^2}. \tag{1}$$

To determine the pressure drop Δh_{local} from the pressure drop Δh_{opt} measured during the test, the pressure losses due to friction drag were eliminated which equaled the corresponding losses of the developed turbulent streams in pipes of the same diameter and length. Taking account of the customary notation, the magnitude of the local drag coefficient was determined by the following dependences:

upon a sudden diminution of the pipeline cross section

$$\xi_2 = \frac{2g\Delta h_{opt}}{v_2^2} - 1 + \left(\frac{d_2}{d_1}\right)^4 - \frac{L_1}{d_1}\left(\frac{d_2}{d_1}\right)^4 \lambda_1 - \frac{L_2}{d_2}\lambda_2, \tag{2}$$

where

$$p_1 - p_2 = \gamma\Delta h_{opt} > 0;$$

upon a sudden increase in the pipeline cross section

$$\xi_1 = 1 - \left(\frac{d_1}{d_2}\right)^4 - \frac{L_1}{d_1}\lambda_1 - \frac{L_2}{d_2}\left(\frac{d_1}{d_2}\right)^4 \lambda_2 + \frac{2g\Delta h_{opt}}{v_1^2}, \tag{3}$$

where

$$p_1 - p_2 = \gamma\Delta h_{opt} < 0;$$

upon the presence of elbows, a gate valve, or washers in the pipeline

$$\xi = \frac{2g\Delta h_{opt}}{v^2} - \frac{L}{d}\lambda, \tag{4}$$

where

$$p_1 - p_2 = \gamma\Delta h_{opt} > 0.$$

The data obtained as a result of measurements and processed by means of formulas (1)-(3) for the magnitude of the local drag coefficient of all the kinds of shaped parts considered herein are presented in Figs. 1-4. The dashes in these same figures represent the computed values of these same coefficients [4, 5], which agree well with the experimental results.

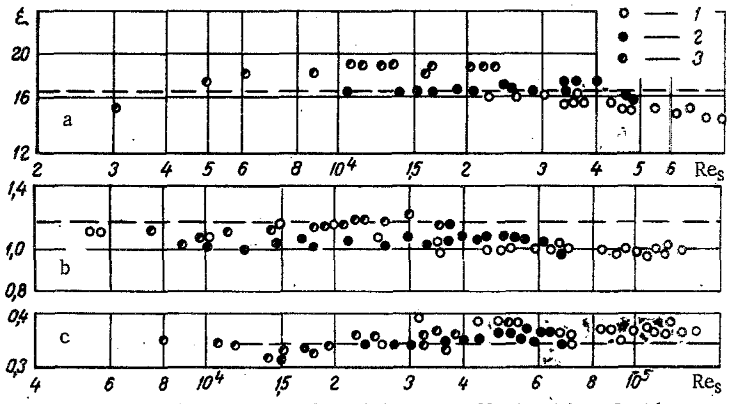

Fig. 2. Dependence of the local drag coefficient $\xi = 2g\Delta h_{local}/v^2$ of washers of $d_0 = 26.5$ mm (a), $d_0 = 41.5$ mm (b), and $d_0 = 54$ mm (c) diameter in a flow of water and polyox in a $d = 70$ mm diameter pipeline: 1) water; 2) polyox solution, $c = 10^{-3}$ g/cm^3; 3) polyox solution, $c = 2 \cdot 10^{-3}$ g/cm^3; dashes are the computation [4, 5]. The ordinate axis in Fig. a should be 1.2, 1.6, 2.0.

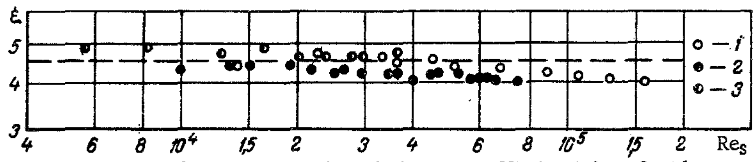

Fig. 3. Dependence of the local drag coefficient $\xi = 2g\Delta h_{local}/v^2$ of a DU70 gate valve on the Reynolds number $Re_s = vd/\nu_s$ for water and polyox solution flows: 1) water; 2) polyox solution, $c = 10^{-3}$ g/cm^3; 3) polyox solution, $c = 2 \cdot 10^{-3}$ g/cm^3; dashed line is the computed value.

The magnitudes of the friction drag coefficients λ in (2)-(4) were determined in tests with the polyox solutions by the method of converting the efficiency of these solutions to reduce the friction drag [1]. The efficiency of the solutions was checked regularly by means of data on their flow in a constant section pipeline of $d = 20.9$ mm diameter.

As is seen from the results presented (Figs. 1-4), the polymer admixtures in a water flow exert no substantial influence on the magnitude of the local drag coefficients. To verify the validity of the deductions obtained, the total drag of a specific hydraulic system [1], operating in a closed cycle (from a pump) and containing various turning elbows with 30-180° angles of rotation in various stream planes, two wedge-like gates, a washer with a quarter circle profile and two tanks, a head and a discharge tank, in addition to straight pipelines of diameters 35.5, 70.0, and 100 mm, was investigated.

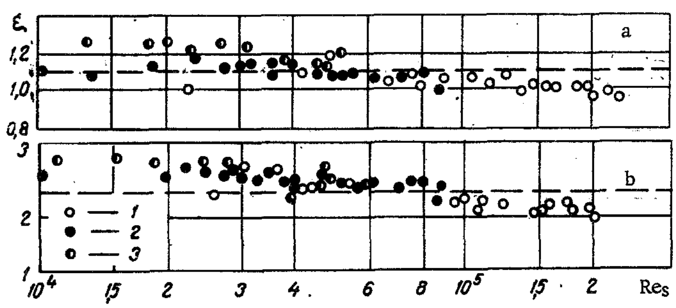

Fig. 4. Dependence of the local drag coefficient $\xi = 2g\Delta h_{local}/v^2$ on the Reynolds number $Re_s = vd/\nu_s$ for water and polyox solution flows in a 90° (a) and Z-shaped (b) elbow of $d = 50$ mm diameter (b): 1) water; 2) polyox solution, $c = 10^{-3}$ g/cm^3; 3) polyox solution, $c = 2 \cdot 10^{-3}$ g/cm^3; dashed line is the computation [5].

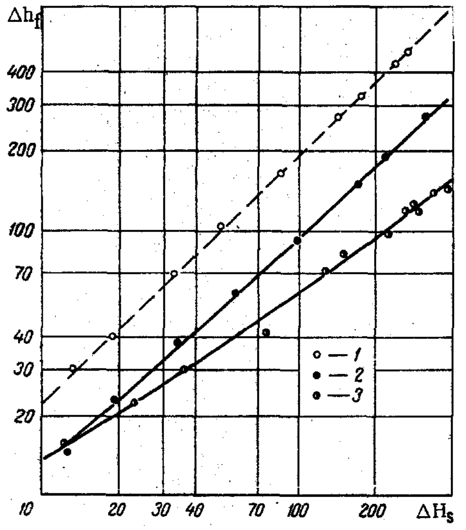

Fig. 5

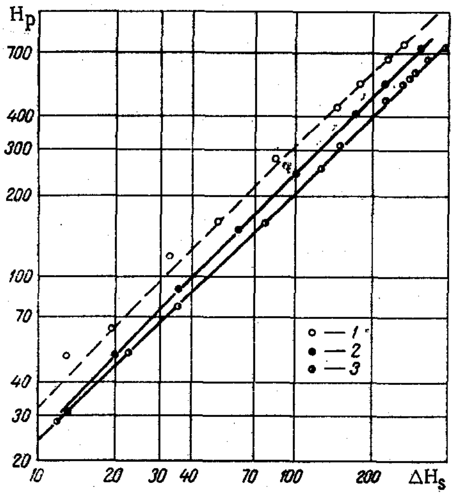

Fig. 6

Fig. 5. Dependence of the quantity Δh_f (mm Hg), proportional to the friction force, on Δh_s (mm Hg), proportional to the square of the fluid discharge in the pipeline: 1) water; 2) polyacrylamide solution, $c = 1.4 \cdot 10^{-5}$ g/cm^3; 3) polyox solution, $c = 10^{-3}$ g/cm^3.

Fig. 6. Dependence of the pressure drop in the pump H_p (mm Hg) on ΔH_s (mm Hg), proportional to the square of the fluid discharge in the hydraulic apparatus: 1) water; 2) polyacrylamide solution, $c = 1.4 \cdot 10^{-5}$ g/cm^3; 3) polyox solution, $c = 10^{-3}$ g/cm^3.

The computation of the hydraulic system was reduced to the following dependence of the magnitude of the pressure head H_p produced by the pump on the magnitude of the mean water flow velocity v in the working pipeline (d = 35.5 mm):

$$H_p = \left(2.3 + \frac{3}{v^{1/4}}\right) \frac{v^2}{2g} . \tag{5}$$

The first member is the total magnitude of the local drags of the system under consideration, computed by means of known dependences [4]. The second member is the total magnitude of the friction coefficients of all the straight pipeline sections in the system.

The computations performed according to (5) agree well with the experimental data obtained for water flow in a hydraulic apparatus (Fig. 6).

In the case of a flow of polymer solutions in a hydraulic system, it should be expected that the magnitude of the local drag coefficients would remain unchanged. However, the friction drag in a stream of polymer solutions changes substantially as compared with the water stream and a correction to the coefficient $3/v^{1/4}$ should be introduced in (5):

$$H_p = \left(2.3 + \frac{3k}{v^{1/4}}\right) \frac{v^2}{2g} , \tag{6}$$

where

$$k = \frac{\Delta h_{f(\text{polymer})}}{\Delta h_{f(\text{water})}} \quad \text{for } v = \text{const} \; (\text{for } \Delta H_s = \text{const})$$

is the correction coefficient taking account of the value of the reduction in friction drag in the stream of polymer solution.

Computations by means of (6), where the coefficient k was determined from results of measuring the friction drag in water and polyacrylamide and polyox solutions of concentrations $c = 1.4 \cdot 10^{-5}$ g/cm^3 and $c = 10^{-3}$ g/cm^3, respectively (Fig. 5), showed good agreement with the experimental results obtained in tests with these solutions (Fig. 6).

Therefore, the deduction about the independence of the magnitude of the local drag coefficients on the presence of polymer admixtures in a sufficiently high concentration ($c = 10^{-3}$ g/cm^3) in the water stream is confirmed by the experimental results of measuring the total magnitude of these coefficients in a specific hydraulic apparatus.

NOTATION

H_p	is the pressure drop in the pump;
ΔH_s	is the pressure drop in the flow meter;
Δh_f	is the pressure drop in the measured section of a rectilinear pipeline;
p_1	is the static pressure ahead of the local drag;
p_2	is the static pressure behind the local drag;
$p_1 - p_2 = \gamma \Delta h_{opt}$;	
Δh_{local}	is the pressure drop directly at the local drag;
d	is the pipeline diameter;
d_1	is the pipeline diameter ahead of the local drag;
d_2	is the pipeline diameter behind the local drag;
v	is the mean discharge velocity in a pipeline of diameter d;
v_1	is the mean discharge velocity before the local drag;
v_2	is the mean discharge velocity behind the local drag;
d_0	is the least jet diameter during contraction;
$Re_s = (vd/\nu)$	is the Reynolds number;
λ	is the friction drag coefficient;
ν_s	is the kinematic viscosity of the solution;
ν_w	is the kinematic viscosity of water.

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