AN EXPERIMENTAL INVESTIGATION OF THE EFFECT OF A POLYACRYLAMIDE ADDITIVE ON THE PRESSURE DROP IN AN EXPANSION

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The results are presented of an experimental investigation of the pressure drop in expansions with various cone angles during the turbulent flow of aqueous polyacrylamide solutions.

By introducing into a liquid flow an additive which reduces turbulent friction it is possible to achieve a considerable reduction in the losses of energy during the motion of solids in water and in the transport of liquids in pipelines [1, 2]. Among such additives are known high molecular weight polymers, micelle-forming surface-active materials, fibers, and other small anisometrically shaped particles. Under turbulent flow conditions of the stream, the additive causes a reduction in the friction losses per unit length [2]. The effect of the additive on the value of local losses is more complex in nature. Depending on the specific conditions of the liquid flow the additive can lead to a decrease or an increase in the local pressure drop in a pipeline [3-6]. The study of the effect of additives on the values of the local losses is of practical interest in the design and operation of pipeline systems for various purposes.

The objective of the present work was to investigate the pressure-drop behavior of pipeline expansions (diffusors) in the presence of a polyacrylamide (PAA) additive in the aqueous stream.

Interchangeable expansions with cone angles α equal to 10, 15, 20, 30, 40, 60, 80, and 140° were investigated; these were installed by means of threaded and flanged connections between the ends of tubes with diameters d = 5.81 mm and D = 20.95 mm, and has corresponding values of the diameters of the inlet and outlet openings. Sudden tube expansions were formed from coaxial flanged connections of tube sections of constant diameter D = 20.95 mm with interchangeable tubes of diameters d equal to 5.81, 10.68, and 15.64 mm. The degree of expansion of the stream $n = (D/d)^2$ therefore had values of 13.0, 3.85, and 1.79. The sudden tube expansions were studied as special cases of the diffusor-type expansions in which the cone angle became equal to 180°. The tube material was stainless steel. A sketch of the experimental pipeline is shown in Fig. 1. The length ℓ of the tube of diameter d ahead of the expansion was variable. The experimental results are given for ℓ = 180d. The pressure drops in the measuring sections of the experimental pipeline were measured with water differential pizeometers to an accuracy of 1 mm H_2O.

In preparing the solutions, use was made of polyacrylamide (PAA) type TU 6-01-1049-81 in the form of a technical gel. A weighed portion of the PAA gel was placed in a glass cylinder with tap water (pH = 7.65) preheated to 35-40°C where it dissolved with periodic mixing after some days. After the completion of the dissolution of the PAA, the contents of the cylinder were poured into tanks of capacity 0.2 and 0.4 m³, and were carefully mixed with tap water. The aqueous solutions of PAA which were obtained were held for 15-24 h, and were again mixed before the beginning of the experiment. The mass concentrations of the solutions, C, as determined from the content of PAA of 100% concentrations in them, valued from 10^{-7} to $5 \cdot 10^{-4}$. The solutions were used once only. The experiments were carried out with flow of the solution under the influence of gravity. The static head in the experimental pipeline was equal to 3.5 m. The working temperature of the solutions varied in the range 18-23°C. The flow rate of the solution passing through the experimental pipeline was controlled by means of the valve, and was determined by a volumetric measurement.

The effectiveness of the solutions which were investigated was monitored from their effect on the pressure drop in the tube of diameter d. The friction factor λ for the section

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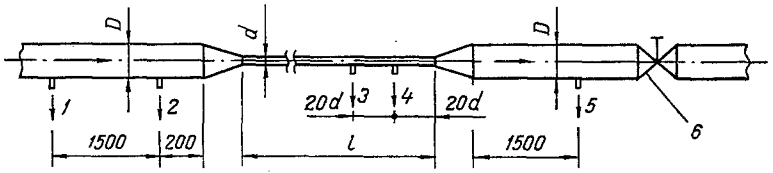

Fig. 1. Sketch of the experimental pipeline. 1-5) Tappings for pressure readings; 6) valve (dimensions in mm).

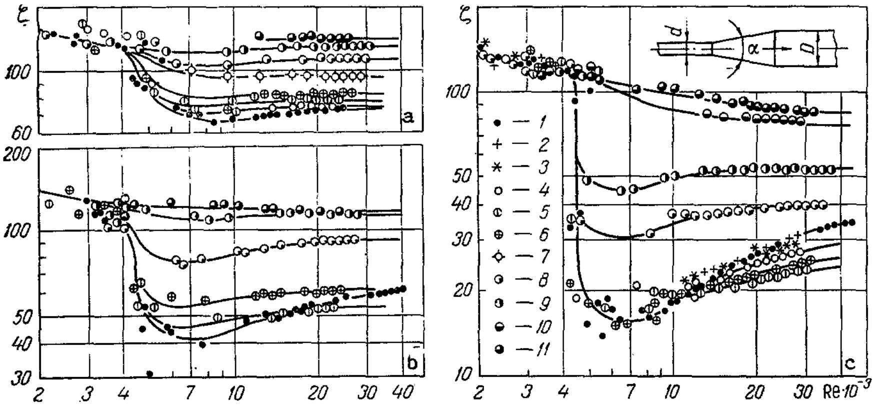

Fig. 2. Resistance coefficient of expansion ζ as a function of the Reynolds number Re at various cone angles (a): α = 30°; b) α = 20°; c) α = 10°) for the flow of water (1) and aqueous solutions of PAA with concentrations 10^{-7} (2); $5\cdot10^{-7}$ (3); 10^{-6} (4); $5\cdot10^{-6}$ (5); 10^{-5} (6); $2\cdot10^{-5}$ (7); $5\cdot10^{-5}$ (8); 10^{-4} (9); $3\cdot10^{-4}$ (10); $5\cdot10^{-4}$ (11); d = 5.81 mm; D = 20.95.

3-4 of this tube (see Fig. 1) was determined from the Darcy–Weisbach formula: $\Delta h_{3-4} = \lambda(\ell_{3-4}/d)(v_d^2/2g)$.

The loss in head in the expansion was calculated from the relationship $h = \Delta h_{4-5} - \Delta h_{1-2} - \Delta h_{3-4} + \alpha_d v_d^2/2g - \alpha_D v_D^2/2g$. In the calculations it was assumed that $\alpha_d \approx \alpha_D \approx 1$. The resistance coefficient of the expansion ζ, referred to the velocity of the stream in the tube cross section of diameter D, was determined from the Weisbach formula, $h = \zeta v_D^2/2g$. In practice, the viscosity of the liquid being investigated differed little from that of the solvent. The kinematic viscosity of the solution, like that of water, was taken to be a function of the temperature of the solution.

Figure 2 shows the graphical relationships ζ = f(Re) for expansions with various values of α and C. For values of the Reynolds number $2\cdot10^3 \leq Re \leq 4.5\cdot10^3$ the PAA additive showed no effect on the value of the coefficient ζ. When $Re > 4.5\cdot10^3$ the additive led to an earlier onset of the self-similariy of the coefficient ζ with respect to the Reynolds number, which occurred in the investigated range of the latter. For the expansion with α = 30°, an increase in the resistance was found which became larger with increase of the solution concentration (Fig. 2a). As the cone angle decreased, there was an expansion of the upper limit of the value of the solution concentration at which the reduction in the pressure drop of the expansion occurs. Thus, for the tube of d = 5.81 mm, the cone angle of which is equal to 0°, a reduction in the pressure drop was obtained at all the investigated concentrations of the PAA solution. A saturation of the pressure drop reduction effect occurs for the tube at $C = 10^{-4}$, and for the expansion with a cone angle of 10° at $C = 5\cdot10^{-6}$ (Fig. 3a). A further increase in the concentration above these values for the tube and expansion, respectively, led to a decrease in the effectiveness of the solution. When $C > 3.5\cdot10^{-5}$, the PAA additive led to an increase in the resistance of the expansion (curve 2). The maximum increase in resistance $\Delta\zeta/\zeta = -143.5\%$ was obtained at $C = 5\cdot10^{-4}$, and the maximum reduction (24.8%) at $C = 5\cdot10^{-6}$-10^{-5}. In the concentration range 10^{-7} to $5\cdot10^{-6}$ the reduction in resistance of the expansion is the same as that in the case of the tube (curves 2 and 3 coincide).

The expansion with a cone angle of 10° was investigated for four values of ℓ: 70, 110, 180, and 250d. The increase of ℓ led to an amplification of the resistance reduction effect at the end section of the tube of diameter d. The same occurs in the expansion at solution

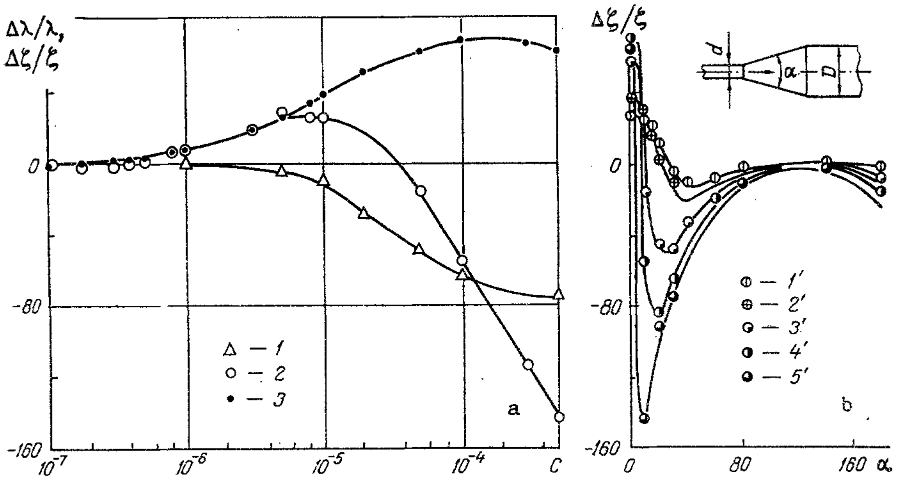

Fig. 3. Relative change in the resistance coefficient of an expansion as a function of the concentration C of the aqueous solution of PAA at various cone angles (a); 1) $\alpha = 30°$; 2) $\alpha = 10°$; 3) curve $\Delta\lambda/\lambda = f(C)$ for tube of d = 5.81 mm, $\alpha = 0°$; and as a function of the cone angle at various concentrations of the aqueous PAA solutions (b): 1') $C = 5\cdot10^{-6}$; 2') 10^{-5}; 3') $5\cdot10^{-5}$; 4') 10^{-4}; 5') $5\cdot10^{-4}$; d = 5.81 mm, D = 20.95 mm. Re = $4\cdot10^{4}$; $\Delta\zeta/\zeta$ and $\Delta\lambda/\lambda$ in %; α in degrees.

TABLE 1. Dependence of $\Delta\zeta/\zeta$ on the Concentration C of the PAA Solution and on the Degree of Expansion of the Stream n

d	D	$n=(D/d)^2$	$\Delta\zeta/\zeta = (\zeta_w - \zeta_p)/\zeta_w$, %				
			C				
mm			10^{-5}	$5\cdot10^{-5}$	$8\cdot10^{-5}$	10^{-4}	$3\cdot10^{-4}$
5,81	20,95	13,0	—	−9,1	−10,9	−16,4	—
10,68	20,95	3,85	—	0	0	0	—
15,64	20,95	1,79	0	—	—	6,8	18,6

concentrations less than 10^{-5}. When $C > 3.5\cdot10^{-5}$ the value of $\Delta\zeta/\zeta$ was independent of the length ℓ.

A decrease in the resistance of the expansion was found for $\alpha \leqq 20°$. At cone angles falling in the range 100-140°, the expansion was least subject to the effect of the additive (Fig. 3b).

The results of the investigations of the sudden tube expansions are given in Table 1. As the degree of expansion of the stream n decreases, a transition from an increase to a decrease in the resistance of the sudden expansion is observed due to the additive. A high concentration of the solution corresponds to a large increase in the resistance coefficient ζ when n = 13.0 and to a large decrease when n = 1.79. The data which are presented here are in agreement with the results of the investigations of B. V. Lipatov [3].

It follows from the data given in Table 1 that it is possible to increase the zone in which the resistance of the expansion decreases, which is shown in Fig. 3b, by decreasing the degree of expansion of the stream n. The existence of a reduction in the resistance arises when a considerable part of the total resistance consists of friction losses [2]. This condition is satisfies at small values of α and n, which explains why there is a reduction in the resistance of the expansion when $\alpha \leqq 20°$ and in the sudden tube expansion for n = 1.79.

It has been shown that the effect of the additive on local pressure losses in pipelines increases as the pipeline diameter decreases [3-13]. The relative change in the coefficient of local friction caused by the presence of the PAA additive in the aqueous stream depends on the concentration of the solution, the cone angle of the expansion, the degree of expansion of the stream, and also on the flow regime, the age of the solution, and the method used for its preparation.

NOTATION

d, D, diameters of the inlet and outlet openings of the expansion and of the tubes attached to them; $n = (D/d)^2$, degree of enlargement of the stream in the expansion; α, cone angle of the expansion; ℓ, length of tube of diameter d leading into the expansion; C, mass concentration of solution; h, head loss in expansion, mm H_2O; Δh_{1-2}, ..., Δh_{4-5}, head losses in the pipe sections 1-2, ..., 4-5, respectively (see Fig. 1); α_d, α_D and v_d, v_D, kinetic energy corrections and mean flow velocities over the cross sections of tubes of diameters d and D, respectively; g, acceleration of free fall; $Re = v_d d/\nu$, Reynolds number; ν, kinematic viscocity; λ, friction factor for tube; λ_w, λ_p, friction factors for flows of water and aqueous polyacrylamide solutions, respectively; ζ, resistance coefficient of expansion (or of sudden tube expansion); ζ_w, ζ_p, the same, for the flow of water and of aqueous polyacrylamide solutions, respectively; $\Delta\lambda/\lambda = (\lambda_w - \lambda_p)/\lambda_w$, $\Delta\zeta/\zeta = (\zeta_w - \zeta_p)/\zeta_w$, relative changes of the coefficients λ and ζ, respectively, caused by the introduction of the polyacrylamide additive under otherwise similar flow conditions.

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