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5.2 The effect of the influence of aqueous ditalan solutions on the friction resistance in the gap between a rotating rotor and a stationary stator

When designing engines, their prototypes are tested on experimental stands. In this case, the load on the shaft is created by hydraulic brakes with an adjustable braking torque. In hydraulic brakes, the rotor is coaxial with the stator, which is filled with a working fluid. The braking moment can be adjusted in three ways: by changing the contact area of the rotor surface with the working fluid; by changing the ratio of ingredients of the working fluid (liquid-gas mixture); by changing the direction of supply of the working fluid in the stator. The contact area of the rotor surface with the working fluid is changed, as a rule, by raising or lowering the stator with the working fluid.

In paper [294], an energy-saving method of regulating the braking torque of a hydraulic brake by changing the eccentricity of the rotor in the working fluid with hydrodynamical active additives (HAA) is proposed. The proposed installation has smaller dimensions and energy consumption of the stator drive and allows the rotor shaft to be placed in any position. The hydraulic resistance of the rotor in the liquid with the HAA is regulated by moving the stator, forming a closed annular confuser-diffuser gap between them (Fig. 1). Hydraulic brakes of this type are also described in the works [295, 296].

A Literature review. The number of scientific papers devoted to the flow of fluids with HAA between coaxial cylinders is not as large as between disks or spheres. Of the analyzed scientific papers on the flow between eccentric cylinders, only two refer to the effect of the HAA [297, 298].

Couette flows with Taylor vortices appear in the gap between the rotor and the stator. Taylor-Couette flow is widely used to study the instability and flow formation in the transition zone and turbulence zone in laboratory conditions.

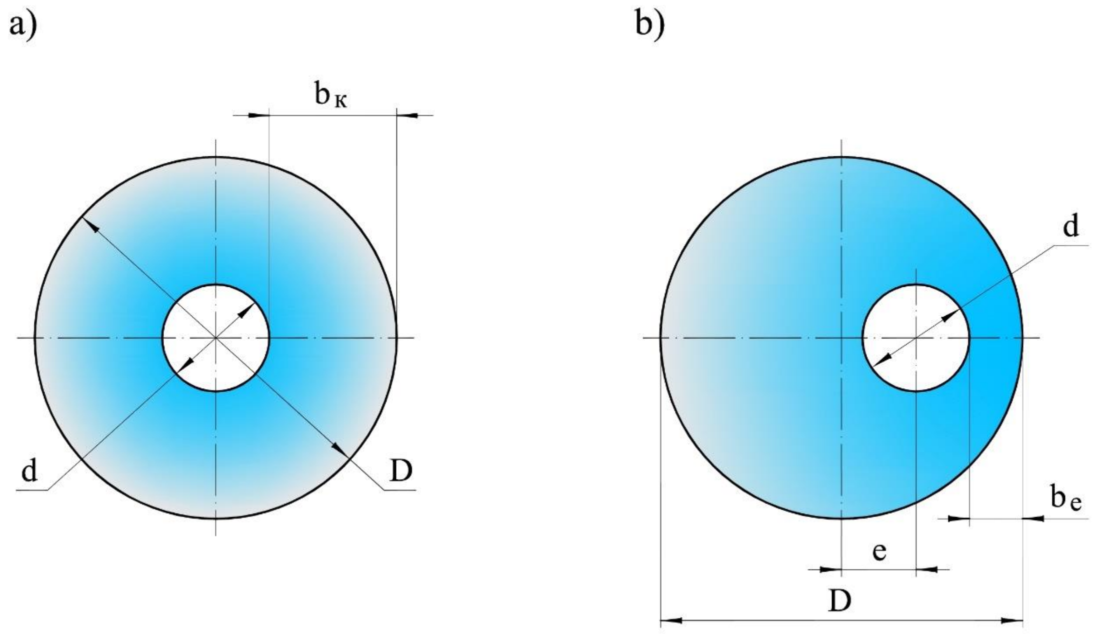


Figure 1. Schemes of rotor and stator arrangement: a) concentric;
b) eccentric; b_k – the width of the gap at the coaxial arrangement of the rotor,
b_e – at the axial; e – eccentricity

Taylor-Couette flow was first investigated by G.I. Taylor, who observed and calculated the critical value of the Reynolds number needed to obtain instability in a one-dimensional solution in this system. These instabilities are cellular toroidal vortices that propagate sequentially along the axis of the cylinder. A. Davey obtained the value of the torque acting on the cylinders by numerical calculation for the Taylor vortex flow [299]. J.A. Cole first observed the second critical Reynolds number and demonstrated it using flow visualization [300]. The visualization shows that with a further increase in the angular velocity (greater than the first critical Reynolds number), a wavelike vortex flow is observed. By measuring the torque, it was proved that the Taylor vortex flow becomes unstable beyond this critical velocity. An increase in the value of the second critical Reynolds number was observed with increasing annular gap, and the values coincided with theoretical predictions for aspect ratios greater than 40. R.J. Donnelly and N.J. Simon [301] developed a mathematical relationship for the torque through fluid friction against the outer cylinder as a function of the angular velocity of the inner cylinder and verified it with experimental data. F. Wendt used the dimensionless torque to scale the torque and developed an empirical relation for the Taylor-Couette system [302].

Surfactants have a strong potential for drag reduction, but they are not widely studied compared to high molecular weight polymers. Unlike polymers, surfactants substances have the advantage of displacement resistance in displacement in pumps and other high stress zones. Surfactants have the ability to self-healing, which gives them an advantage over polymers [303]. The decrease in the resistance obtained in the case of surfactants flow may be higher than polymers [304].

The Taylor-Couette system was widely studied to reduce resistance using additives, and various surface modifications were investigated [305, 306]. A number of studies have been conducted to reduce the resistance of the Taylor-Couette flow using polymers, surfactants, etc. [307, 308].

Experimental research. Experimental stand.

The scheme of the experimental stand is presented in fig. 2. A detailed description of the experimental stand is presented in [309]. The installation consists of a stator 1, which is pivotally mounted on a plate 2, which reciprocates in the groove 3 of the base of the plate 4. The plate is set in motion by a threaded screw 5 and a handle 6. A rotor 7 is installed in the cavity of the stator 1, which is connected by a shaft 8 to an electric motor 9. The electric motor is rigidly attached to the base plate 4. The shaft 8 is passed through the hole in the impermeable cover 10, which is fixed on the stator 1. The stator consists of a metal frame 11 with holes inside which a transparent cylinder 12 is rigidly fixed. In the bottom of the stator 1, the axis 13 is pressed, which is installed in the bearing installed on the plate 2. The experimental stand is equipped with a device for converting alternating current into direct current. To measure the rotation velocity of the rotor, a tachometer 14 was used, which is in contact with the end of the motor shaft 9. The inner diameter of the stator was 142 mm and rotor – 42.1 mm.

The experimental stand allows to study fluid flows in an annular or closed confuser-diffuser gap between cylinders at different values of eccentricity, cylinder diameters, rotor rotation velocity and various parameters of the working fluid.

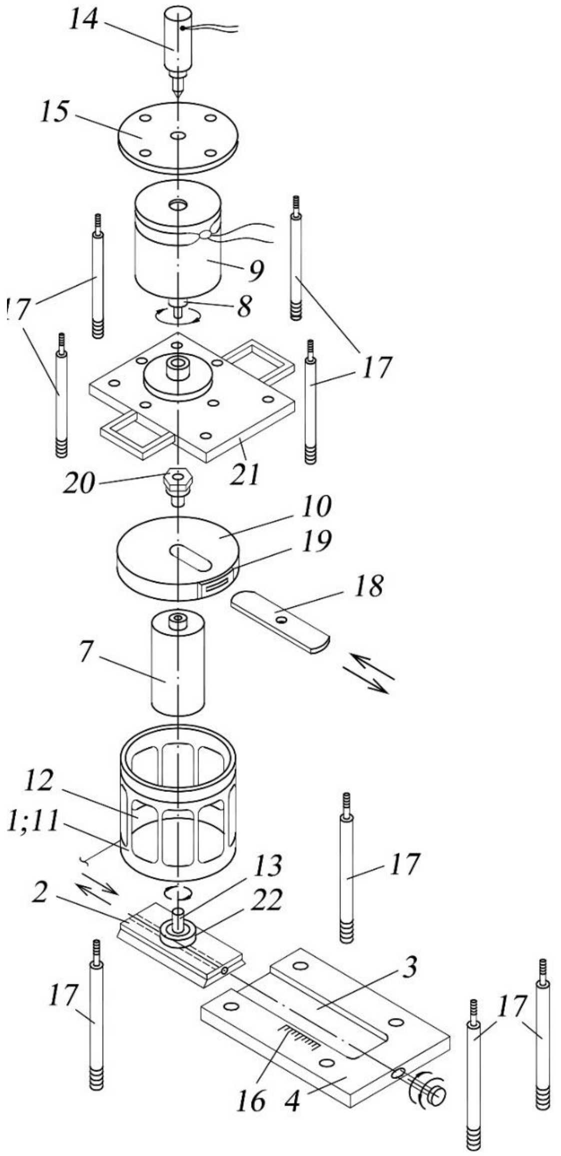


Figure 2. Scheme of the experimental stand: 1 – stator; 2 – plate; 3 – groove; 4 – base plate; 5 – threaded screw; 6 – handle; 7 – rotor; 8 – shaft; 9 – electric motor; 10 – cover; 11 – metal frame; 12 – transparent cylinder; 13 – axis; 14 – tachometer; 15, 21 – plates; 16 – scale; 17 racks; 18 – sealing plate; 19 – seals; 20 – intermediate sleeve; 22 – clips [309]

Experiments were carried out at values of the relative width of the gap b_e/b_k = 0.265...1.0 (Table 1).

Selection of working fluid. Flows of water and aqueous ditalan solutions with mass concentrations C = 10^{-2} and $8 \cdot 10^{-2}$ kg/ kg were studied. For thickening, 3% of their weight of sodium chloride (NaCl) was added to ditalan solutions and for stabilization – 0.2% of sodium hydrogen carbonate ($NaHCO_3$).

Table 1

The values of the relative gap width were studied

Diameters, mm		d/D	Eccentricity e, mm	Relative gap width $b_e/b_к$
Rotor diameter d	Stator diameter D			
42.1	142	0.30	0	1.00
			12	0.755
			24	0.51
			36	0.265

Calculation formulas.

The braking torque acting on the inner cylinder was calculated indirectly through the engine power consumption:

$$M = \frac{N \cdot 60}{2\pi \cdot n}, \quad (1)$$

where n – number of rotor revolutions.

The average tangential stresses on the rotor wall are determined by formula:

$$\tau = \frac{T}{2\pi \cdot r \cdot H}, \quad (2)$$

where T – the total friction force applied to the side surface of the rotor:

$$T = M/r,$$

where r – rotor radius;

H – rotor height.

The water flow regime is characterized by the Taylor criterion:

$$Ta = \frac{V \cdot b}{\nu} \cdot \sqrt{\frac{b}{r}}, \quad (3)$$

where V – linear rotation velocity of the rotor;

ν – kinematic viscosity of the liquid.

The friction coefficient in the gap between the rotor and the stator was determined as:

$$C_f = \frac{G}{Re^2}, \tag{4}$$

where G – dimensionless torque on the inner cylinder in the gap between the rotor and the stator,

$$G = \frac{T}{\rho \cdot \nu^2 \cdot H}; \tag{4}$$

where ρ – liquid specific gravity.

Reynolds criterion determined by formula:

$$Re = \frac{\Omega \cdot r \cdot (r_o - r)}{\nu}. \tag{5}$$

where r_o – stator radius;

Ω – angular rotation velocity of the rotor.

The relative change in the coefficient of friction was determined as:

$$DR\% = \frac{c_{f,\omega} - c_{f,s}}{c_{f,\omega}} \times 100, \tag{6}$$

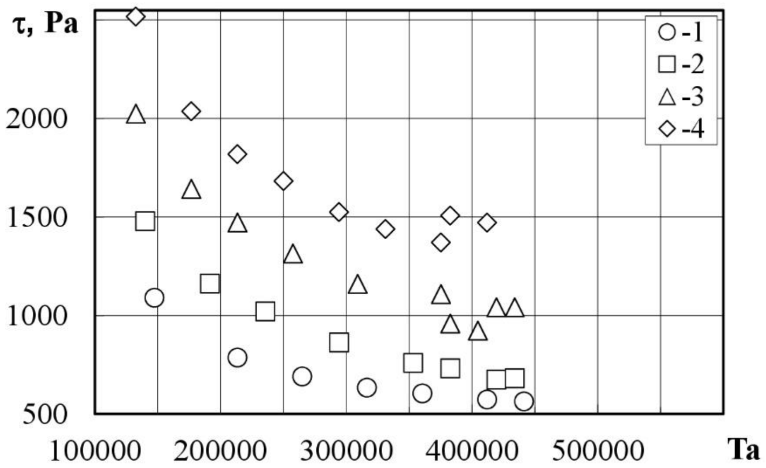
where $c_{f,\omega}$ – coefficient of friction in the gap between the rotor and the stator during water flow; $c_{f,s}$ – coefficient of friction in the gap between the rotor and the stator during water with ditalan additives flow.

Results and discussion. This paper presents the results of the influence of eccentricity and concentrations of aqueous ditalan solutions on the hydrodynamic resistance of the rotor. Each of the obtained points is the arithmetic mean of three repeated measurements.

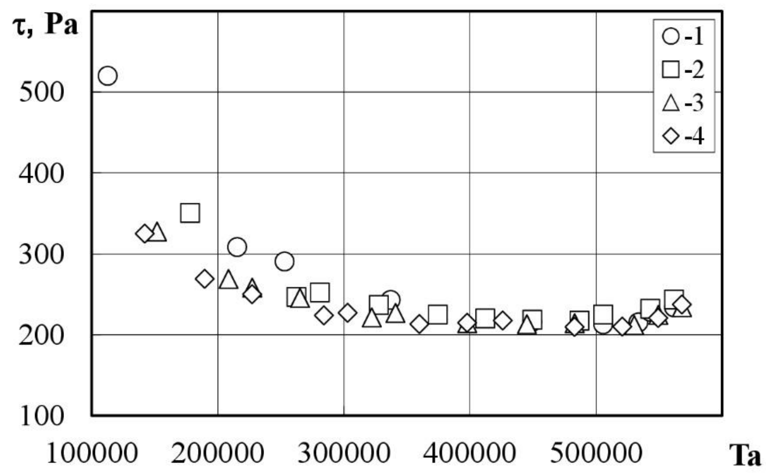
Graphic dependences of τ = f(Ta) for the flow of aqueous ditalan solutions in the gap between cylinders for d/D = 0.30 and b_e/b_k = 0.265; 0.51; 0.755; 1.0 is presented in fig. 3.

For the studied range of values of the Taylor criterion Ta = 100000...600000, the average tangential stresses on the wall of the rotor, which rotated in water and in aqueous ditalan solutions (Fig. 3, b, c), decrease with an increase in the criterion Ta and with a decrease in the ratio b_e/b_k, i.e. with increasing eccentricity e (Fig. 1).

a)



b)



c)

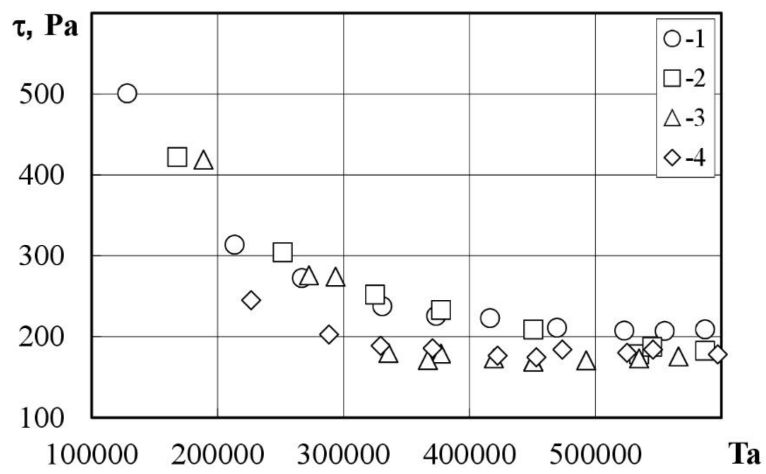
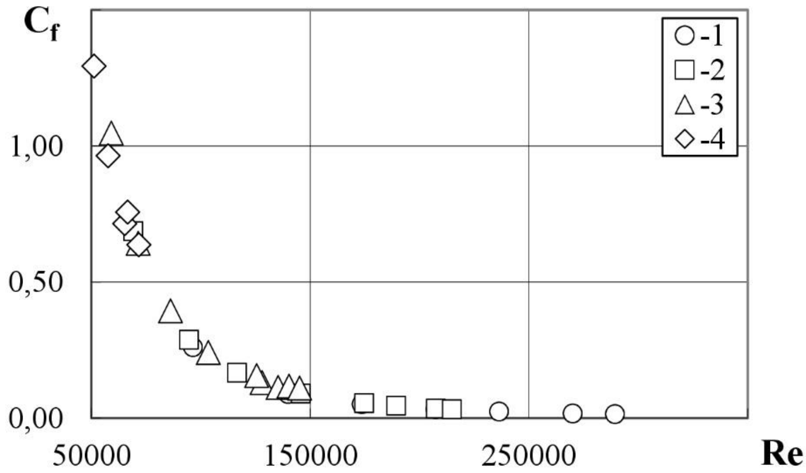
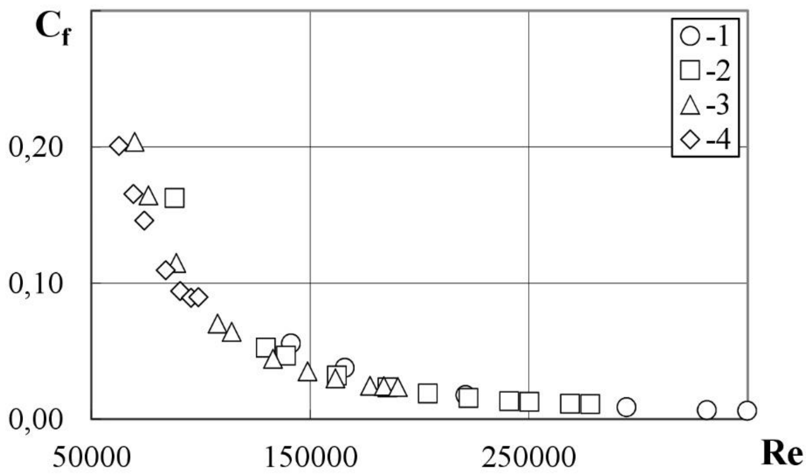


Figure 3. Dependence of tangential stresses τ on Taylor criterion Ta and eccentricity: 0 mm (1); 12.0 mm (2); 24.0 mm (3); 36.0 mm (4) for a rotor diameter of d = 42.1 mm, which rotated in water (a) and aqueous ditalan solutions with mass concentrations of 1% (b), 8% (c)

a)



b)



c)

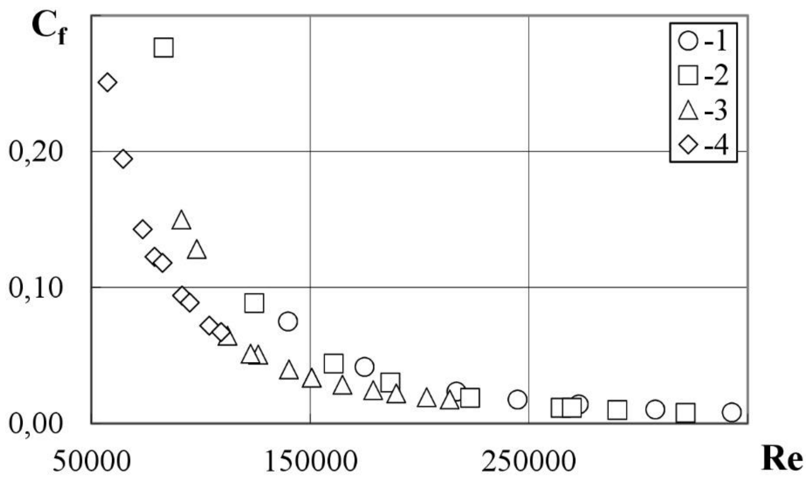


Figure 4. Dependence of the coefficient of friction C_f in the gap between the rotor and the stator on the Reynolds criterion Re and eccentricity: 0 mm (1); 12.0 mm (2); 24.0 mm (3); 36.0 mm (4) for water (a) and aqueous ditalan solutions with mass concentrations of 1% (b), 8% (c)

During water flow, the tangential stresses on the rotor wall (d/D = 0.30) for all investigated values of b_e/b_k increase. Additions of ditalan reduced the tangential stresses on the rotor wall at the coaxial arrangement of the cylinders ($b_e/b_k = 1$) for the studied aqueous ditalan solutions mass concentrations. With an eccentric arrangement of the rotor, its hydraulic resistance increased for all values of b_e/b_k (Table 2). Additions of ditalan of the investigated concentrations caused a change in the resistance of the rotor.

Table 2

The influence of an and non-coaxial rotor location on its hydraulic resistance at Ta = 400000

$b_e/b_к$	Tangential stresses on the rotor wall τ, Pa, at the concentration of an aqueous ditalan solution C, %		
	0	1.0	8.0
1.0	570	220	215
0.265	1370	215	175

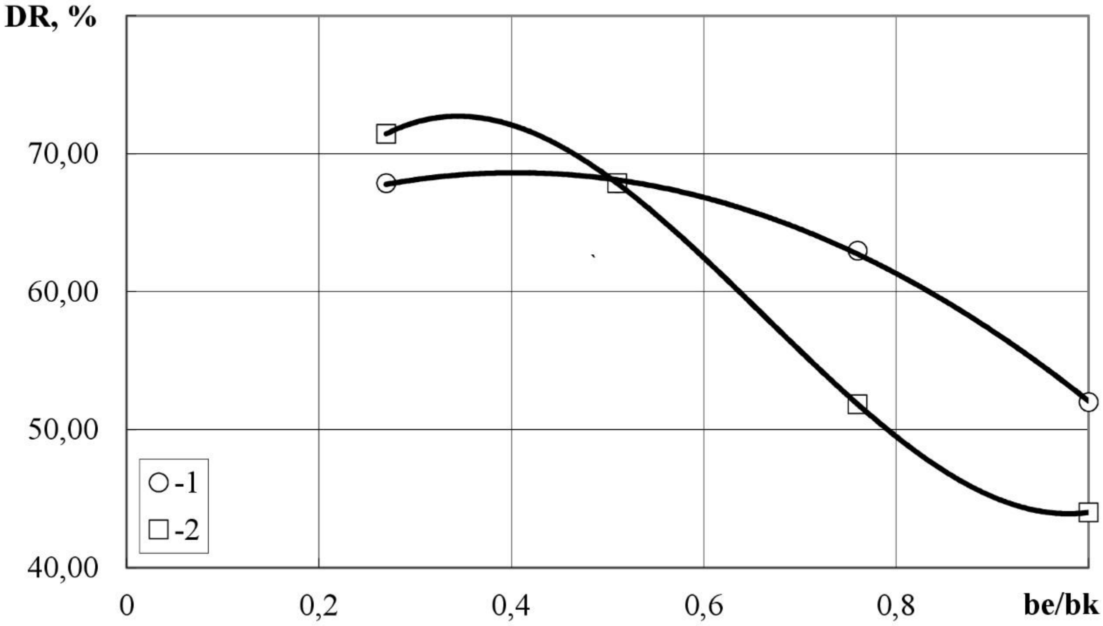
On fig. 4 presents the results of the change in the coefficient of friction for water and aqueous ditalan solutions (C = 1.0%, 8.0%) at relative gap widths b_e/b_k = 1.0; 0.755; 0.51; 0.265. As the Reynolds number increases, the friction coefficient decreases for the investigated concentrations of aqueous ditalan solutions. For fixed values of the Reynolds number, a decrease in the friction coefficient of the studied solutions was obtained with a decrease in the width of the gap.

The effect of DR aqueous solutions of ditalan on the frictional resistance of the rotor at Re = 100000 decreases with increasing values of b_e/b_k, starting from b_e/b_k = 0.51 for studied concentrations C = 1.0% and 8.0%, respectively (Fig. 5). In addition, decreasing the concentration from 8.0% to 1.0% weakens this effect at b_e/b_k = 0.51 and more, and at b_e/b_k = 0.51 and less, the effect is reversed.

At value of Reynolds number Re = 200000, the effect of DR of aqueous ditalan solutions on the frictional resistance of the rotor with a decrease in concentration from

8.0 to 1.0% is weakened this effect for all investigated values of b_e/b_k.

a)



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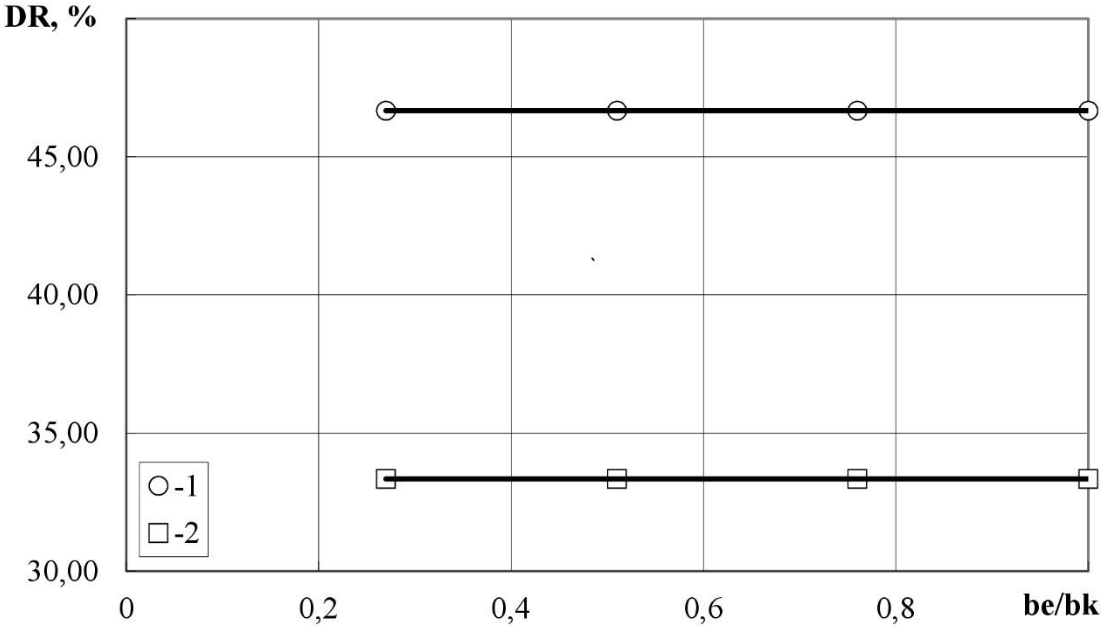

Figure 5. Dependence of the relative friction coefficient on the relative width of the gap b_e/b_k for aqueous ditalan solutions with concentrations of 1% (1) and 8% (2) at Re = 100000 (a) and 200000 (b)

The effect of aqueous ditalan solutions with mass concentrations C = 1.0% and 8.0% on the frictional resistance in the gap between the rotor and the stator at d/D = 0.30 for b_e/b_k = 1.0; 0.755; 0.51; 0.265 was revealed.

The obtained results confirm the possibility of adjusting the braking moment of the hydraulic brake by changing the eccentricity between the rotor and the stator, including in the presence of hydrodynamical active additives in the working fluid. The braking torque of the rotor in water and in aqueous solutions of HAA depends on their concentration and is regulated by changing the eccentricity of the rotor.