# KAPITEL 7 / CHAPTER 7 [7]

# EFFECT OF THE ECCENTRICITY OF A CYLINDRICAL ROTOR RELATIVE TO THE STATOR ON HYDRAULIC RESISTANCE IN AQUEOUS METAUPON SOLUTION

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## Introduction

Testing of engines of different types is carried out using loads produced by hydraulic brakes. These brakes are most commonly used in bench studies due to their simple design, high energy consumption, and the ability to adjust a wide range of loads and rotor revolutions compared to mechanical and electric brakes [1, 2]. In such brakes, the engine's energy is used to overcome friction forces between the rotor and working fluid and working fluid and the stator wall.

Chernyuk V., Pasichniuk A., and Hnativ R. invented a method for regulating the braking torque of a hydraulic brake by changing the eccentricity of the rotor in the working fluid with hydrodynamically active additives [3]. This brake has smaller dimensions and energy consumption compared to existing ones, and it allows for arbitrary orientation of the rotor shaft in space. When the stator moves, a closed annular confuser-diffusor gap is formed between the rotor and the stator, enabling the regulation of hydraulic resistance of the rotor in a liquid with hydrodynamically active additives (Fig. 1).

## 7.1. Literature review

Fluid flows between the stator and the rotor, which are located inside the stator, can also be observed in mixers, rotary viscometers, drill pipes, and bearings [4-7]. These flows have been studied with the coaxial arrangement of the rotor and stator [8-10]. Studies have also been conducted on fluid flows between a cone and a ball [11] and the hydraulic resistance of spherical rotors [12, 13]. Additionally, there are known studies devoted to the flow between non-coaxial cylinders, located externally relative to each other [14, 15]. In [16], the results of experiments on the movement of the working fluid in angular contact bearings with an eccentric shaft position are presented, but with a laminar fluid flow mode.

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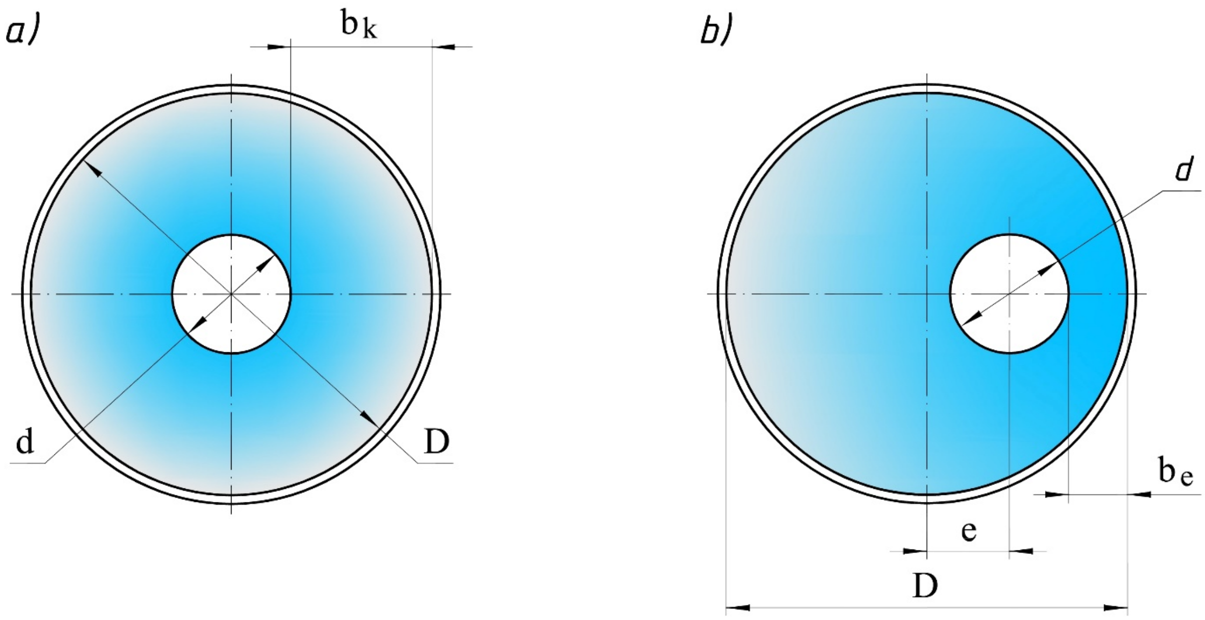


**Figure 1. Schemes of rotor and stator arrangement: a) concentric; b) eccentric; $b_k$ – the width of the gap at the coaxial arrangement of the rotor; $b_e$ – at the axial; e – eccentricity**

Hydrodynamically active additives have found wide practical application [17]. Polymer additives increase the compactness and range of fire-fighting jets [18], reduce energy losses in heat networks [18], oil pipelines [19], irrigation systems [20], and sewer networks [21].

The use of hydrodynamically active additives also enables the mitigation of cavitation effects [21], reduction of blood pressure [22], and increase in the speed of ships [23].

## 7.2. Experimental research

### *7.2.1. Experimental stand*

A detailed description of the experimental setup can be found in [24]. The setup comprises a stator (1) hinged onto a plate (2), which moves back and forth within a groove (3) on a base plate (4). A threaded screw and handle drive the plate's motion. A rotor (5) is positioned within the stator (1) cavity and connected to an electric motor (7) through shaft (6), which is securely fixed to the base plate (4). Shaft (6) passes through a hole in the impermeable cover (8), also fixed to the stator (1). An axis (11) is pressed into the bottom of the stator (1) and installed in a bearing mounted on plate (2). The experimental setup is equipped with a device for converting alternating current into direct current. To measure the rotor's rotational speed, a tachometer (12) was employed, which came into contact with the end of the electric motor's shaft. The stator's inner diameter measures D = 142 mm, and the rotor's diameter at its height (H = 153 mm) is d = 26.3 mm.

**Table 1. The values of the relative width of the gap between the rotor and the stator were studied**

| Diameters, mm | | d/D | Eccentricity e, mm | Relative gap width $b_e/b_k$ |
|---|---|---|---|---|
| Stator diameter D | Rotor diameter d | | | |
| 142 | 26,3 | 0,18 | 0 | 1.00 |
| | | | 15 | 0.72 |
| | | | 30 | 0.46 |
| | | | 40 | 0.29 |
| | | | 50 | 0.12 |

### *7.2.2. Working fluid selection*

In this study, we investigated the flows of water and aqueous solutions of Metaupon (Metaupon OMT, produced by Walter Ulbricht, Germany) with mass concentrations of 0.1%, 0.5%, and 1.0%. To thicken these solutions, we added 7% of their weight in sodium chloride (NaCl), and for stabilization, we added 0.2% of sodium hydrogen carbonate ($NaHCO_3$). Stabilization was performed to prevent the loss of hydrodynamic activity. The temperature of the investigated solutions ranged from 25.5°C to 30.0°C.

The purpose of this work is to experimentally study the effect of the eccentricity of a cylindrical rotor relative to the stator on the hydrodynamic resistance in aqueous solutions of Metaupon.

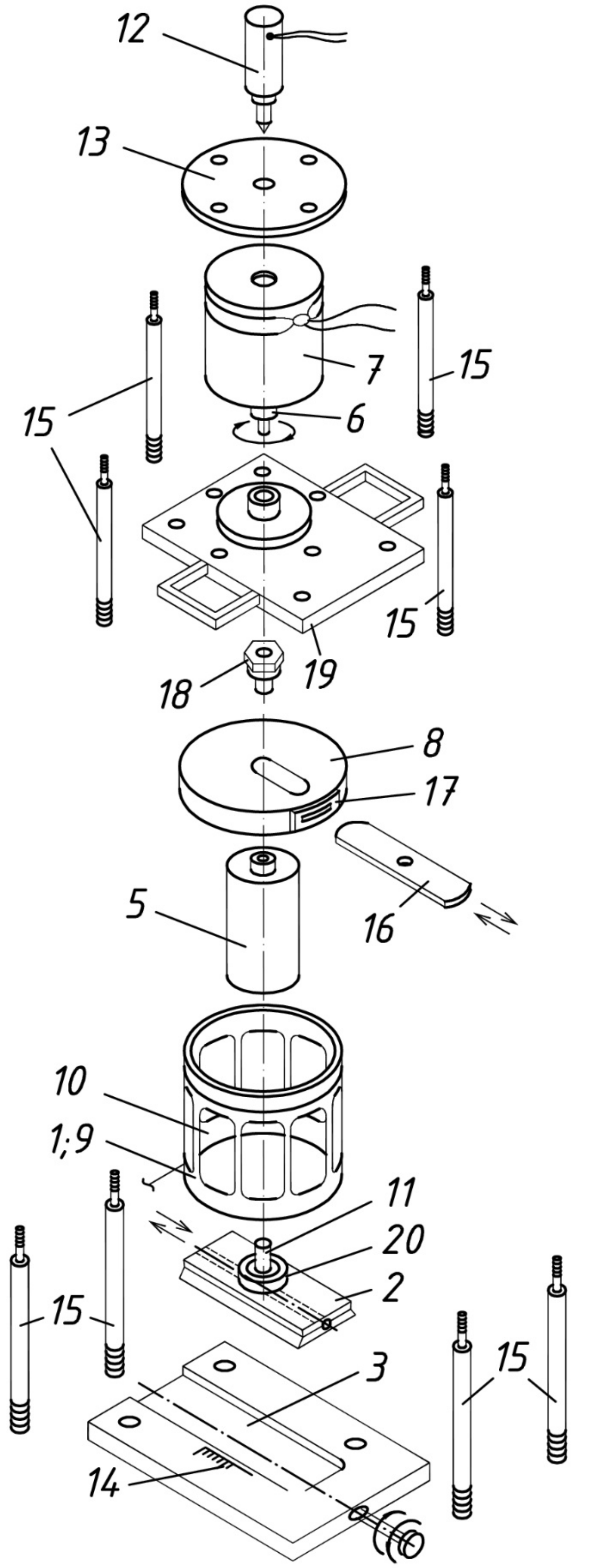


**Figure 2. Scheme of the experimental stand:**
**1 – stator;**
**2 – movable plate;**
**3 – groove;**
**4 – base plate;**
**5 – rotor;**
**6 – shaft;**
**7 – DC electric motor;**
**8 – cover;**
**9 – metal frame;**
**10 – transparent cylinder;**
**11 – axis;**
**12 – tachometer;**
**13 – plate;**
**14 – scale;**
**15 – stand;**
**16 – sealing plate;**
**17 – seals;**
**18 – intermediate sleeve;**
**19 – plate;**
**20 – clamp**

### *7.2.3. Calculation formulas*

Average tangential stresses τ on the wall of the rotating cylinder are determined by dependence:

$$\tau = \frac{T}{(2\pi \cdot r \cdot H)}, \quad (1)$$

where T – the total friction force applied to the side surface of the rotor; r – rotor radius (r = ½·d); H – rotor height.

$$T = \frac{M}{r}, \quad (2)$$

where M – braking torque acting on the rotor.

$$M = \frac{N \cdot 60}{\Omega}, \quad (3)$$

where N – power consumption of the electric motor; Ω – rotor angular rotation speed.

$$N = I \cdot U, \quad (4)$$

where I – current strength; U – voltage.

$$\Omega = 2\pi \cdot n, \quad (5)$$

where n – number of rotor revolutions.

The coefficient of friction in the gap between the rotor and the stator:

$$C_f = \frac{G}{\mathrm{Re}^2}, \quad (6)$$

where G – dimensionless torque on the inner cylinder in the gap between the rotor and the stator; Re – Reynolds number:

$$G = \frac{T}{\rho \cdot \nu^2 \cdot H}, \quad (7)$$

where ρ – water specific gravity; ν – kinematic viscosity of the water.

Reynolds number:

$$\mathrm{Re} = \frac{\Omega_i \cdot r_i \cdot (r_o - \mathrm{r}_i)}{\nu}, \quad (8)$$

where $r_o$ – radius of the stator, $r_o$ = ½·D.

Taylor criterion:

$$\mathrm{Ta} = \frac{V \cdot b}{\nu} \cdot \sqrt{\frac{b}{r}}, \quad (9)$$

where V – linear rotor rotation velocity; b – the width of the confuser-diffusor gap between the rotor and the stator:

$$b = (r_o - r) - e, \quad (10)$$

where e – eccentricity (Fig.1, b).

### *7.2.4. Results and discussion*

The experiments were carried out using the experimental setup (Fig. 2) for different ratios of $b_e/b_k$, namely 0.12, 0.29, 0.46, 0.72, and 1.00, as detailed in Table 1.

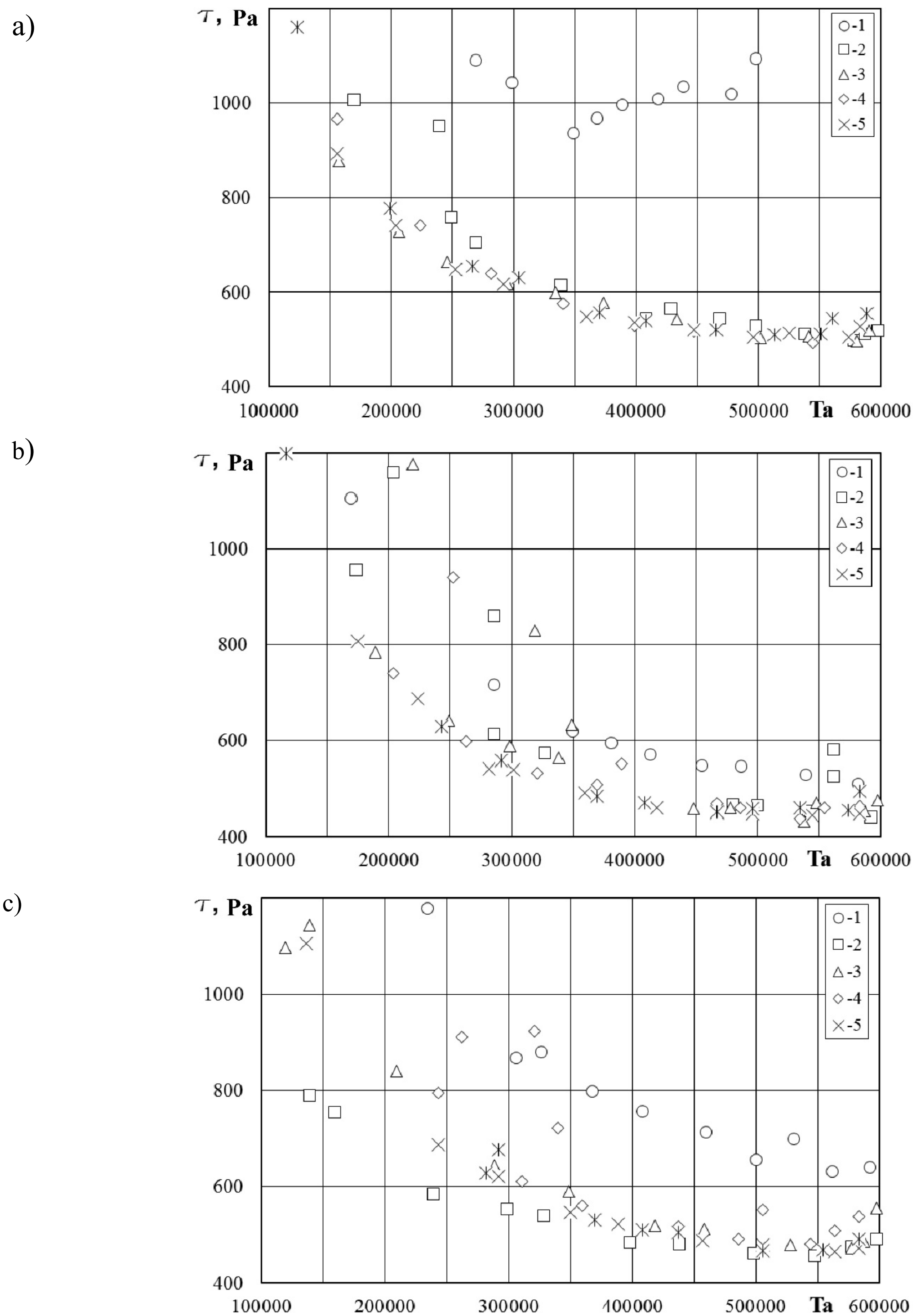


**Figure 3. Influence of the rotor eccentricity (d = 26.3 mm) during rotation in Metaupon solutions at various mass concentrations: 0.1% (a); 0.5% (b); 1.0% (c) for gap width $b_e/b_k$ = 1.0 – (1); 0.72 – (2); 0.46 – (3); 0.29– (4); 0.12 – (5)**

This paper presents the results of studying the influence of eccentricity and the concentrations of aqueous solutions of Metaupon with mass concentrations of 0.1%, 0.5%, and 1.0% on the hydrodynamic resistance of the rotor. Measurements were conducted three times, and each data point represents the average arithmetic value.

Figure 3 displays the dependency graphs of $\tau = f(Ta)$ for the flow of aqueous solutions of Metaupon in the gap between the cylinders for d/D = 0.18 and various $b_e/b_k$ ratios: 0.12, 0.29, 0.46, 0.72, and 1.00.

The average tangential stresses on the wall of the rotor, which rotated in water and in aqueous solutions of Metaupon, within the investigated range of values of the Taylor criterion (Ta = 100,000 to 600,000, as shown in Fig. 3 a, b, c), decrease with an increase in the Taylor criterion and a decrease in the ratio $b_e/b_k$, i.e., with increasing eccentricity e (as illustrated in Fig. 1).

During water flow, the tangential stresses on the rotor wall (d/D = 0.18) increase for all investigated values of $b_e/b_k$.

The addition of Metaupon increased the tangential stresses on the rotor wall with a coaxial arrangement of the cylinders ($b_e/b_k = 1$) at C = 0.1% and decreased them at C = 0.5% and 1.0%. With an eccentric arrangement of the rotor, its hydraulic resistance increased for all studied values of $b_e/b_k$ (refer to Table 2). Additions of Metaupon at all investigated concentrations caused a change in rotor resistance.

Figure 4 presents the results of the change in the coefficient of friction for aqueous solutions of Metaupon (C = 0.1%, 0.5%, 1.0%) at different relative gap widths ($b_e/b_k$ = 0.12, 0.29, 0.46, 0.72, 1.00).

With increasing values of the Reynolds criterion, the friction coefficient decreases for all investigated concentrations of aqueous solutions of Metaupon. When the Reynolds number is held constant, a decrease in the friction coefficient was observed for the investigated solutions as the gap width decreased, as also noted in studies [25-28].

The effect of DR aqueous solutions of Metaupon on rotor friction resistance at Re = 150,000 decreases with increasing values of $b_e/b_k$, within the ranges of 0.12-0.29 and 0.72-1.0 for concentrations of C = 0.1% and 1.0%, respectively (as shown in Fig. 5, a). For C = 0.5%, it decreases when $b_e/b_k$ = 1.0. In the range $b_e/b_k$ = 0.29-0.72, the effect does not change.

At Re = 200,000, the influence of DR aqueous solutions of Metaupon decreases for all investigated concentrations, beginning at $b_e/b_k$ = 0.46 (as depicted in Fig. 5, b). Notably, the influence of DR aqueous solutions of Metaupon is consistent at concentrations C = 0.1% and 0.5%.

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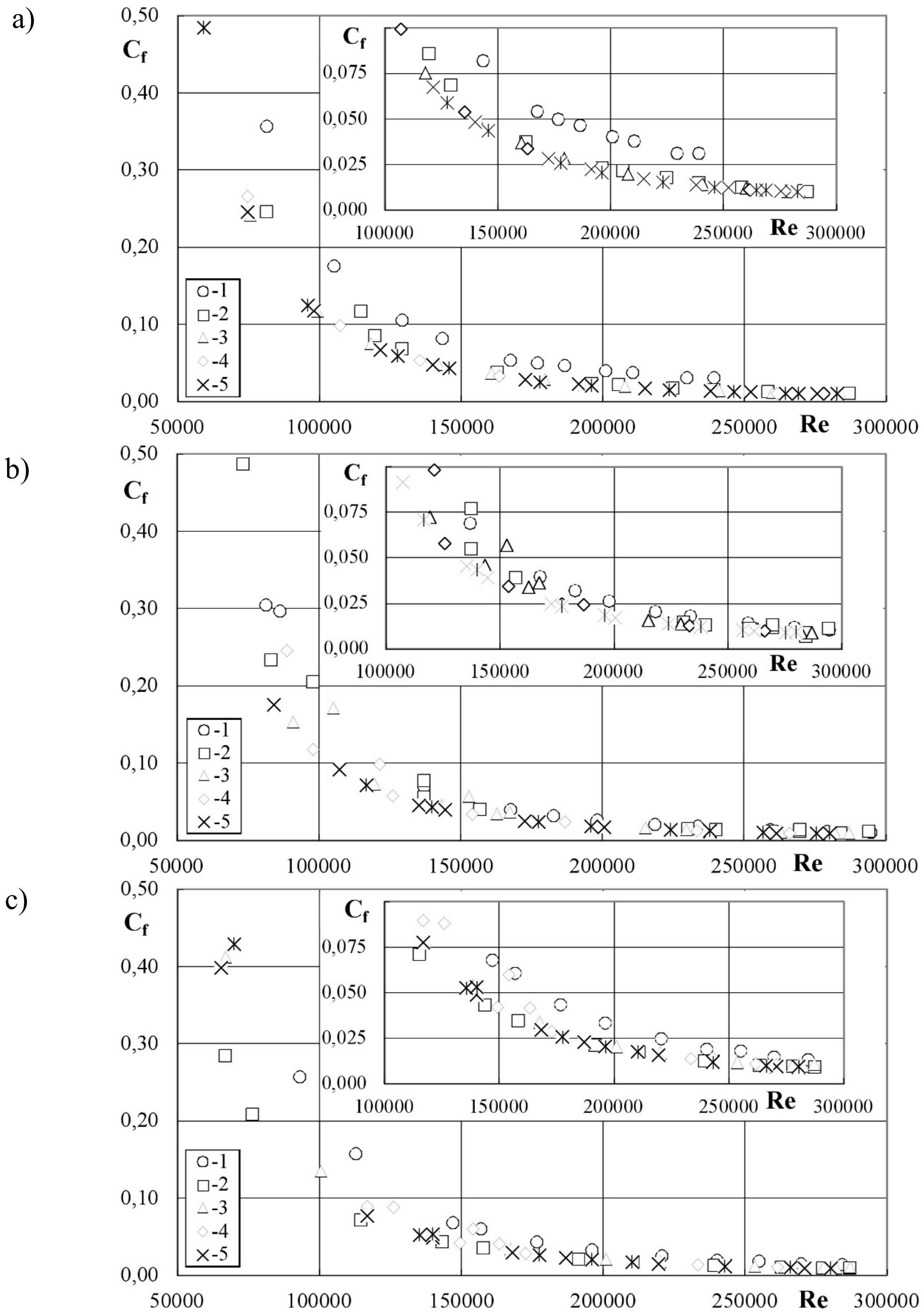


**Figure 4. Influence of the rotor eccentricity (d = 26.3 mm) during rotation in Metaupon solutions at various mass concentrations: 0.1% (a); 0.5% (b); 1.0% (c) for gap width $b_e/b_k$ = 1.0 – (1); 0.72 – (2); 0.46 – (3); 0.29– (4); 0.12 – (5)**

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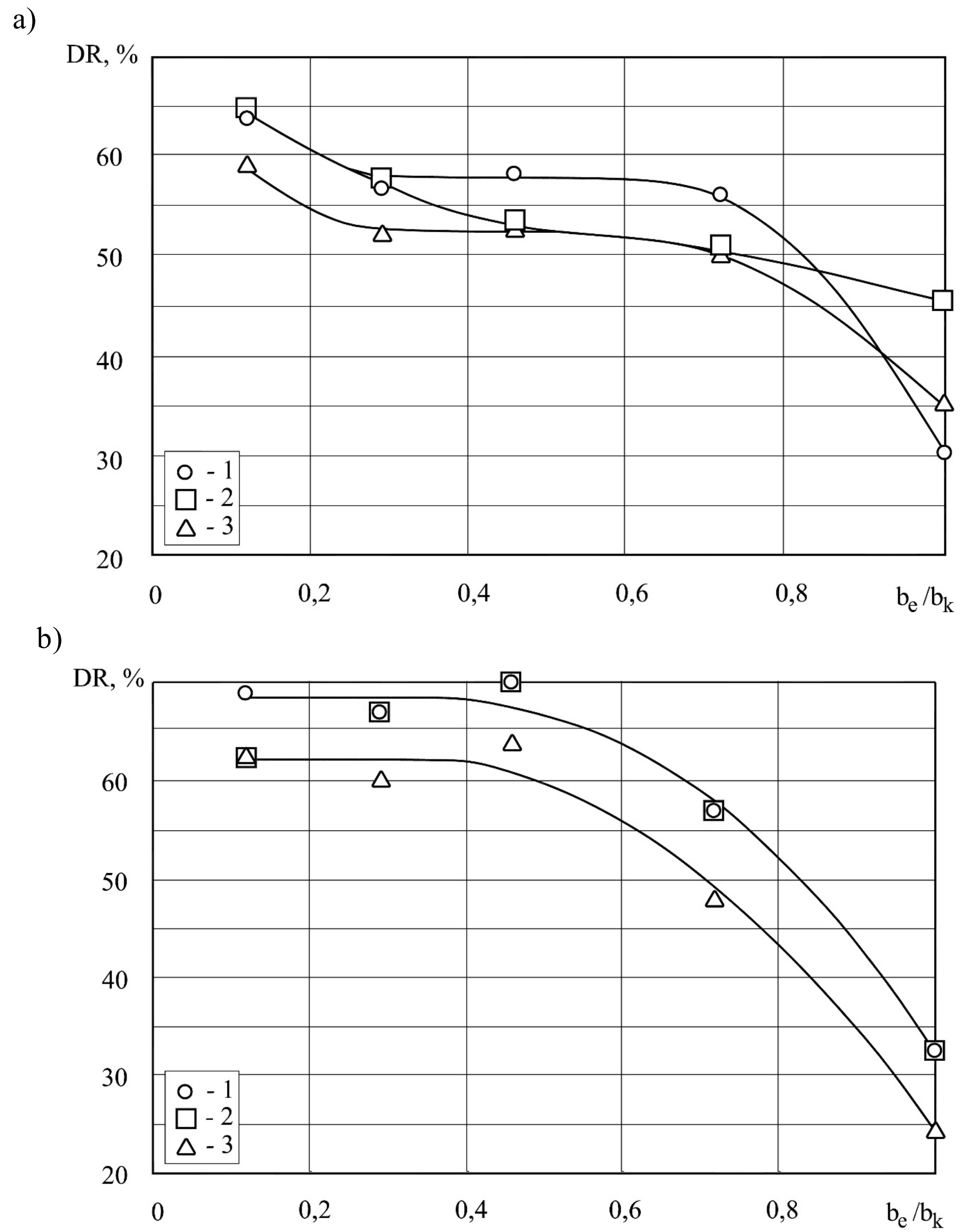


**Figure 5. Influence on frictional resistance at the relative gap width ($b_e/b_k$) for aqueous solutions of Metaupon with mass concentrations of 0.1% (1), 0.5% (2), and 1.0% (3) at Reynolds numbers of 150,000 (a) and 250,000 (b)**

**Table 2. The influence of an eccentric rotor location on its hydraulic resistance at Ta = 550,000**

| $b_e/b_k$ | Tangential stresses on the rotor wall τ, Pa, at the concentration of an aqueous Metaupon solution C, % | | | |
|---|---|---|---|---|
| | 0 | 0.1 | 0.5 | 1.0 |
| 1.0 | 930 | 1020 | 515 | 630 |
| 0.12 | 1250 | 505 | 455 | 470 |

## Conclusions

1. The relationship between the hydrodynamic efficiency of Metaupon and solution concentration has been confirmed.

2. A decrease in the friction coefficient with increasing Reynolds criterion was observed for all investigated eccentricity values.

3. The impact of aqueous solutions of Metaupon with mass concentrations of C = 0.1%, 0.5%, and 1.0% on frictional resistance in the gap between the rotating rotor and the stationary stator at d/D = 0.18 and $b_e/b_k$ = 0.12, 0.29, 0.46, 0.72, and 1.0 was revealed.

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