

HYDRAULIC CHARACTERISTICS OF THE MOTION AND SETTLING OF SLURRY PARTICLES IN THE FOREBAYS OF PUMPING STATIONS

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Abstract. The article analyzes the hydraulic regime of water flow and the processes of motion and sedimentation of slurry (suspended) particles in the forebays of pumping stations within water management systems. Based on scientific studies and practical experiments, the influence of forebay geometry, flow velocity, the number of operating pumps, and the hydraulic size of slurry particles on sediment formation is examined. It is shown that slurry deposits negatively affect the operational efficiency of pump units, with sediments predominantly accumulating in the downstream part of the forebay and along the side slopes. The obtained results substantiate the necessity of improving forebay design and rationally organizing sediment removal measures to ensure reliable and efficient operation of pumping stations.

Keywords: pumping station, forebay, water intake structure, slurry particles, sedimentation, flow regime, hydraulic velocity, pump efficiency

ГИДРАВЛИЧЕСКИЕ ХАРАКТЕРИСТИКИ ДВИЖЕНИЯ И ОСАЖДЕНИЯ ЧАСТИЦ ШЛАМА В ПОДВОДЯЩИХ КАМЕРАХ НАСОСНЫХ СТАНЦИЙ

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Аннотация. В статье анализируется гидравлический режим течения воды и процессы движения и осаждения частиц шлама (взвешенных веществ) в подводящих камерах насосных станций водохозяйственных систем. На основе научных исследований и практических экспериментов изучено влияние геометрии подводящей камеры, скорости потока, числа работающих насосов и гидравлической крупности частиц шлама на процесс осадкообразования.

Показано, что отложения шлама негативно влияют на эффективность работы насосных агрегатов, при этом осадки преимущественно накапливаются в нижней части подводящей камеры и вдоль боковых откосов. Полученные результаты обосновывают необходимость совершенствования конструкции подводящих камер и рационального планирования мероприятий по удалению осадков для обеспечения надёжной и эффективной работы насосных станций.

Ключевые слова: насосная станция, подводящая камера, водозаборное сооружение, частицы шлама, осаждение, режим течения, гидравлическая скорость, эффективность насоса.

INTRODUCTION. In water management systems, the structures located between the end of the water supply canal and the suction pipes of the pumps at pumping stations are called water intake structures. These structures include the forebay (advance chamber) and the intake chamber (Figure 1). At some small pumping stations, the intake chamber may be absent, and in such cases the pumps draw water directly from the forebay through the suction pipes.

In water management systems, the forebays of pumping stations are usually constructed with a conical angle of 30–45°. Their bottom slope, directed from the canal toward the intake chamber, typically has an average gradient of $i = 0.2$ [1].

In these forebays, under almost all operating modes of the pumping station, a transit flow forms in the central part, while water circulation zones appear along the sides. In some cases, eddies develop in these circulation zones, causing air to be drawn in, which negatively affects the operation of the pumps [1].

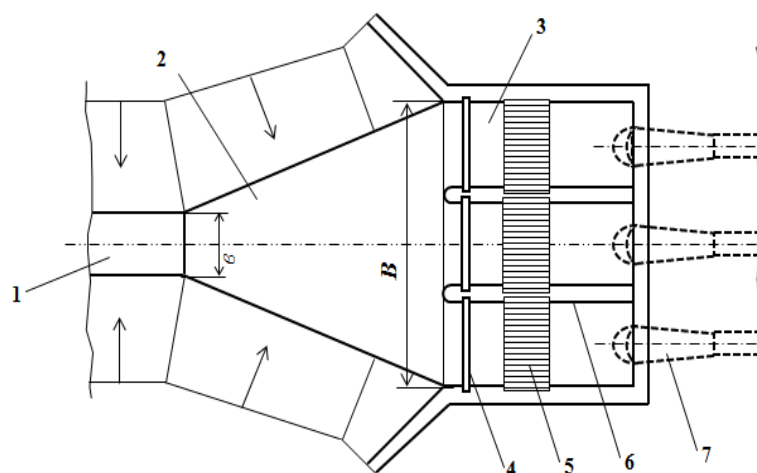


Figure 1. Water intake structure of a pumping station

1 – Water supply canal; 2 – Forebay; 3 – Intake chamber; 4 – Water gate; 5 – Trash rack;
6 – Chamber central walls; 7 – Suction pipes.

According to the research conducted by M. Mukhamadiev, B. Urishev, and F. Nosirov, in the water circulation zones of forebays, the flow velocity is in most cases lower than the critical settling velocity of the slurry particles. As a result, thick sediment deposits form along the two side walls at the downstream end of the forebay [2]. The studies also showed that the number of simultaneously operating pumps has a significant effect on sedimentation. In some cases, sediment deposits can occupy 46–52% of the forebay volume [2].

MAIN BODY. The movement of slurry particles in a water flow is considered complex. Particles transported by the flow are influenced by pulsating velocities with varying directions, while simultaneously moving toward the bottom of the structure under their own weight. If the flow velocity drops below the critical settling velocity, the particles begin to settle collectively [3]. As a result, the inflow into the intake chambers becomes more difficult, a complex flow hydraulic structure forms, and the pump's efficiency and water delivery capacity can decrease by 5–6% [4,5]. In particular, sedimentation can significantly reduce the water supply to pumps located at the edges of the forebay. Research by Prof. M. Mamadzhonov showed that, due to the pressure of sediment in the intake chambers, the pump water delivery capacity can decrease by 4.0% [5]. In such cases, the hydraulic resistance coefficient at the suction pipe inlet can increase from 0.51–0.55 to 0.62–0.67.

In the pumping stations of our republic, the sediment particles in the water flow mainly consist of silt and sand particles, which are grouped according to their sizes. The main parameters of these particles include their size, hydraulic diameter, settling velocity, and degree of contamination (the number of particles per unit volume).

In this regard, it is advisable to use data from Waterman, a company specializing in water purification [6] (Table 1).

Main characteristics of settling particles

Table 1

№	Type of settling particles	Particle size, mm	Hydraulic fall velocity, mm/s	Time to settle 1 m depth
1	Coarse sand	1.0	100	10 s
2	Medium sand	0.5	53	20 s
3	Fine sand	0.1	6.9	2.5 min
4	Coarse mud	0.050–0.027	1.7–0.5	10–30 min
5	Coarse mud	0.010–0.005	0.070–0.017	4–18 h
6	Hard mud	0.0027	0.005	2 days
7	Soft mud	0.0010–0.0005	0.00070–0.00017	0.5–2 months
8	Colloidal particles	0.0002–0.000001	0.000007	4 years

The main portion of particles settling to the bottom of the forebay consists of particles in groups 1–4 [5].

Research on sedimentation in the forebays of pumping stations related to water management has shown that sediments mainly accumulate at the end section of the forebay along the two side slopes and the bottom, and sometimes their thickness can exceed 1.0 meter. Therefore, it is advisable to carry out sediment cleaning works precisely in these locations.

Studies conducted with the participation of the author at the Yoldosh Pumping Station in the Qashqadaryo region showed that the flow velocity in the forebay arises depending on the values of water discharge and the number of pumps operating. Figure 2 depicts the directions and distribution of flow velocity in the pumping station forebay. At the end of the forebay, in almost all operating modes, circulating

zones with velocity values of 0.15–0.2 m/s appear along both sides, and the main sediment deposits mainly correspond to these zones.

Analysis of the literature and sources shows that the process of sediment particles settling to the bottom of structures depends on the particles' hydraulic size, density, and the flow velocity [2,8]. When the flow velocity is lower than the critical velocity that causes sedimentation, particles with a density greater than that of water begin to settle to the bottom of the forebay, provided that there are no pulsating movements in different directions at that location.

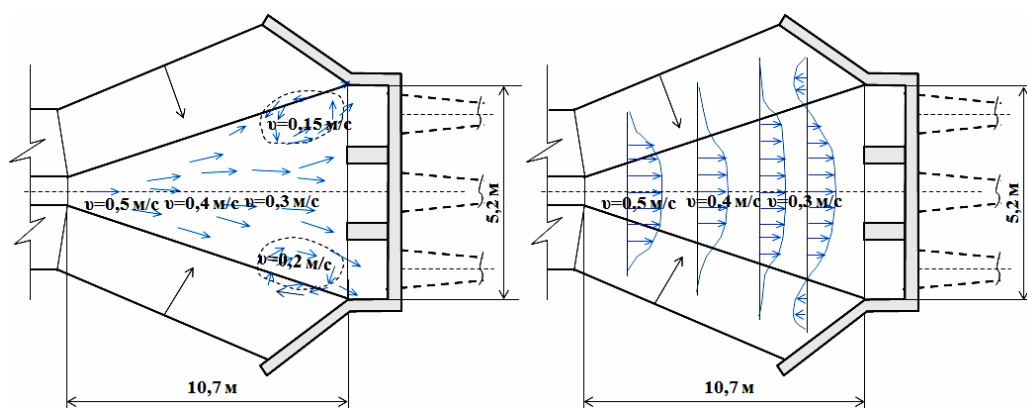


Figure 2. Flow pattern and velocity distribution in the forebay of the Yoldosh pumping station

Prof. I.I. Levi also links particle movement in a flow to many other factors [7]. According to him, the turbulence intensity of the flow plays a significant role, and particles with the same hydraulic size can settle at different locations. He proposes expressing their maximum settling distance using the following function [7].

$$L_{max} = f(\vartheta, d, \mu, \rho_{s.p}, V_0) \quad (1)$$

where ϑ – flow velocity; d – particle size; μ – kinematic viscosity coefficient; $\rho_{s.p}$ – sediment particle density; V_0 – particle hydraulic diameter.

However, a deeper study of the settling of solid particles in a liquid flow has shown that this process can be influenced by many other factors [7].

These studies have shown that the settling process of solid particles in a liquid medium also depends on the following factors.

1. In addition to the forces acting on particles – drag, gravity, and buoyancy (Archimedes force) – it is also necessary to account for the Magnus force, which causes lateral (transverse) migration of small-sized particles [4,7].

2. It is known that during particle motion, an energy field is generated that depends on the particle's size, density, and velocity. In cases with a high concentration of sediment, this field affects the particle's settling velocity. When particles are close to each other, hydrodynamic and gravitational interactions arise, causing them to move collectively; for example, they may settle as a group. In this process, depending on the flow velocity and the energy dissipation, particles can even combine to form a larger single particle [4,7].

3. If there is any stimulating factor affecting particle motion (such as pulsating velocities in vertical or radial directions), it is necessary to account for the **diffusion of the particles** [4,7].

4. Stochastic nature of particle settling – When studying the settling process of particles, it is necessary to consider its stochastic (random) character. In the forebay, particles vary in shape and size, settle at different speeds in the gravitational field, and in some cases experience pulsating movements in various directions. As a result, the deposit layer is non-uniform and heterogeneous, which must be taken into account in analyses.

The velocity V_p of a single particle moving in a mud flow at low speed, taking into account the resistance and gravitational forces, can be determined using the following basic equation. The total settling velocity of this particle, considering its mass, density, gravitational force, Archimedes force, and resistance forces, is expressed by the following equation [4,7].

$$\frac{dV_s}{dt} = \frac{\Delta\rho \cdot g}{2\rho_p + \rho_{w.f}} - \frac{3 \cdot C_D \cdot \rho_{w.f}}{4(2\rho_p + \rho_{w.f})} |V_s - v| (V_s - v) \quad (2)$$

where V_s - particle settling velocity, $\Delta\rho = \rho_p - \rho_{w.f}$, where ρ_p is the particle density and, $\rho_{w.f}$ is the density of the water flow, C_D – drag coefficient, v – water flow

velocity.

The equation recommended in [7] accounts for the dependence of particle settling velocity in a sediment-laden flow on the Reynolds number.

$$V_s = \frac{g \cdot d^2}{18 \cdot \nu_c} \left(\frac{\rho_p}{\rho} - 1 \right) \frac{1}{1 + 0,15 \cdot \Re^{0,687}} \quad (3)$$

ν_c – kinematic viscosity coefficient.

Another empirical formula for determining the settling velocity of a sediment particle is given in [7].

$$V_s = \frac{1}{2} \left(\sqrt{\left(\frac{36 \cdot \nu_c}{d} \right)^2 + 7,25 \left(\frac{\rho_p}{\rho_{w.f}} - 1 \right) d \cdot g} - \frac{36 \cdot \nu_c}{d} \right) \quad (4)$$

According to the authors, this formula is considered a universal one, providing results close to experimental data.

The settling velocity of solid particles in slowly moving sediment-laden flow given above was obtained for spherical particles. To determine the settling trajectory of such particles in the flow along the x and y coordinates, [7] proposes the following relation based on equation (2).

$$y = \frac{V_s}{Q} \left(A \frac{x^3}{3} + B \frac{x^2}{2} + \omega_1 x \right) \quad (5)$$

where, A and B are constant values determined from the geometric dimensions of the forebay, Q is the water flow rate through the forebay, ω_1 is the cross-sectional area of the flow in the water supply channel, and V_s is the settling velocity, determined using formula (4).

The flow particles in the forebay are not perfectly spherical, so the forces acting on them also vary. In this case, in formula (5), it is necessary to introduce a coefficient K_1 that accounts for the particle shape, as well as a coefficient K_2 that accounts for the sediment concentration. Taking this into account, in [4,7] these coefficients are considered in the form $K_z = K_1 \cdot K_2$ and formula (5) is written in the following form.

$$y = \frac{V_s \cdot K_z}{Q} \left(A \frac{x^3}{3} + B \frac{x^2}{2} + \omega_1 x \right) \quad (6)$$

When the results obtained using this equation are compared with experimental data, it was found that the difference does not exceed 12%. Based on this, it was concluded that equation (6) can be used to determine the settling trajectories of sediment particles in the forebay of pumping stations in water management systems [4,7].

CONCLUSION. The above scientific research results on the hydraulic regime of water flow in the forebay of pumping stations, as well as the movement and settling process of sediment particles, provide important conclusions for improving the efficiency of pumping stations:

1. The conventional forebays currently used in pumping stations of water management systems, which widen and slope at the bottom, cannot distribute the water flow evenly to all suction chambers and pipelines.

2. According to studies on the settling process of sediment particles in forebays, sediment deposits are mainly observed along both sides of the transit flow, settling on the forebay bottom and slopes, with the main deposits concentrated at the rear part of the forebay.

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