Study of operating mode of axial and centrifugal pumps with hydroabrasive wear of parts in flow section of pumping units

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Abstract. To date, a significant amount of work has been done to study the processes of cavitation and hydroabrasive wear in laboratory conditions. Using existing equations for assessing hydroabrasive or cavitation wear leads to certain inaccuracies since the action mechanism underlying them does not correspond to the actual operating conditions of hydraulic machines. Very little has been studied about the issues associated with joint and intense cavitation-abrasive wear, which always occur in full-scale hydraulic machines operating on natural watercourses with high turbidity. So far, the wear of the working bodies of centrifugal and axial pumps has been poorly studied, depending on the mode of their operation, and a methodology has not been developed for selecting operating modes, taking into account the wear of their parts. In this paper, the wear of parts of axial and centrifugal pumps in laboratory conditions is studied, and the dependences of wear on the characteristic dimensions and duration of their operation are given. The results of micrometering of the working parts of the pumps showed that the blades of the impellers along the length and width wear out unevenly both in size and shape. In axial and centrifugal pumps, the most intense wear occurs at the outlet sections of the impeller blades and their sealing elements. When pumping muddy water for 2000 hours, the sealing gaps of type D pumps with a head of 75–80 m are 2.8–3.1 mm. With an increase in the end clearance of the impeller of an axial pump from the impact of a slotted cavitation-abrasive flow, the pressure value and the local concentration of solid particles in the flow play a leading role.

1 Introduction

The dynamics of the increase in the axial pump impeller's end clearance show that the chamber's wear occurs more intensively than the ends of its blades. This is explained by the fact that a pulsating alternating load acts on the surface of the chamber due to the pressure difference on the working and back surfaces of the blades.

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Our experiments in an axial flow pump confirm the linear dependence of the wear ΔG of the parts of the flow path on time T. The concentration of solid particles in the flow should directly relate to the wear rate of the streamlined parts of pumping units.

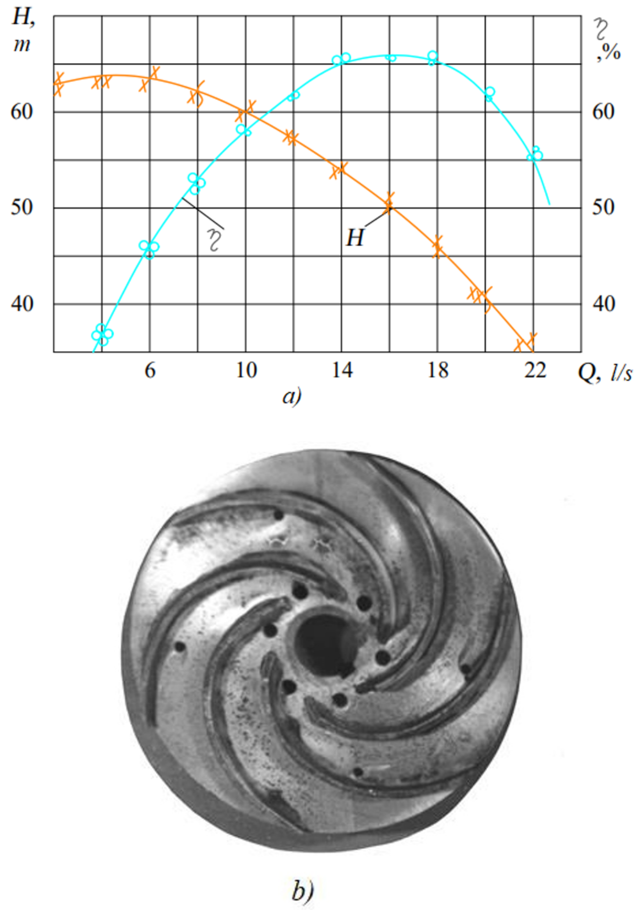

Fig. 1. Characteristics of 3K-6 with centrifugal pump n_o = 2900 rpm *(a)* and its collapsible impeller *(b)*

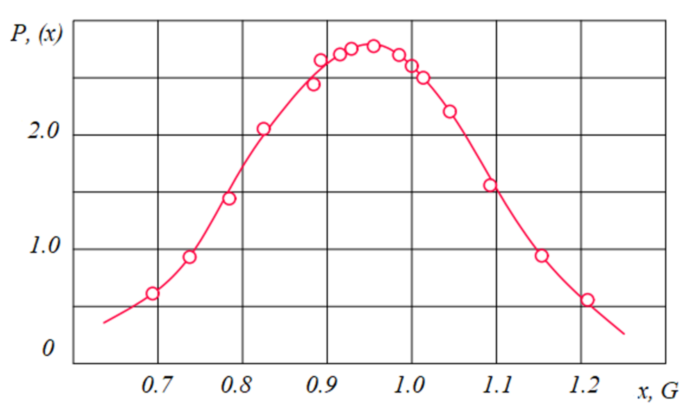

Fig. 2. Probability distribution curve of wear measurement data of impeller blades.

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The results obtained at constant values φ=-30; n_0=1020 rpm; Q=0.297м^3/s; and d_{cp}=0.34 mm, confirmed the rectilinear regularity of the dependence ΔG = f (p) only for such a fixed streamlined part as a straightening vane [1-3].
The total wear of the impeller blade is:

$$\Delta G = \Delta G_n + \Delta G_T = \frac{0.17 A\rho_m \rho^{\frac{3-n}{n+2}} Td}{\Phi^{\frac{5}{n+2}}} \left[\frac{\lambda p Q W^{\frac{10}{n+2}} (\sin\alpha)^{\frac{8-n}{n+2}} \cos\alpha}{ZD} + \right. \quad (1)$$

$$\left. + p_m L W_T^{\frac{12+n}{n+2}} (\cos\alpha)^{\frac{8-n}{n+2}} \sin\alpha \right]$$

where the flow velocity $W_т$ relative to the end part of the impeller [28]:

$$W_T = W_k + u \cdot \sin\beta \quad (2)$$

Experiments carried out at a constant concentration with different fractions of particles d confirmed the linear dependence of the wear of the blades and the pump impeller chamber on the size of solid particles, which is the basis of equation (1). Dependence $\Delta G = f(d)$ of a fixed streamlined part - straightening device - differs from linear [4-7]. Subsequently, all other experiments were carried out at constant values of T=5h, p=10 kg/m^{3,} and d_{cp} =0.34 mm.

A theoretical analysis of the dependence of the hydroabrasive wear of the impeller showed [formula (1)] that the wear rate is significantly affected by the hydrodynamic parameters of the flow in the impeller, determined by the operating mode of the pump.

To identify the experimental dependence of wear on the operating mode of the pump, experiments were carried out at rotation frequencies n_o =600 and 960 rpm. As can be seen from Fig. 3, when the pump is operating with no = 960 rpm. in modes with partial supply (Q< Q_{exp}), with an increase in supply Q, a gradual decrease in the wear of the elements of the pump flow path occurs. The lowest intensity of wear of the blades and the chamber of the impeller and straightener occurs in the optimal for each of the studied values of the angle φ of the installation of the blades, pump operation modes (Q = Q_{on}; η = η_{max}).

As the experiments have shown, it is difficult to single out sharply limited wear zones on its characteristic for an axial pump. When the pump delivery changes by 15-20% from the optimal value, the wear rate increases by 40-80%. This is especially noticeable at large angles of installation of the impeller blades [8-10].

From the theoretical analysis [formula (1)], it has been indicated that in the optimal operating modes of the pump (i.e., η= η_{max}), a smooth flow around the impeller blades is provided, and the coefficient λ will have the smallest value. This leads to a decrease in the wear intensity in the optimal operating modes of the pump. When carrying out experiments in various modes of operation of the pump at n_0 = 960 rpm, in addition to the total mass loss, the wear thickness of the end face ΔG of the end part of the impeller blade was measured simultaneously. Based on the measured data, the dependences of the wear of the end part of the blade on the operating mode of the pump were compiled (Fig. 4). The formula determined the mass loss of the end part $\Delta G_т$ of the blade:

$$\Delta G_т = \rho_m L \cdot \delta \cdot \Delta S_t \quad (3)$$

where ρ_m is the density of silumin; L and δ are the length and thickness of the peripheral profile of the blade, respectively; ΔS_t is the wear thickness of the end part of the blade.

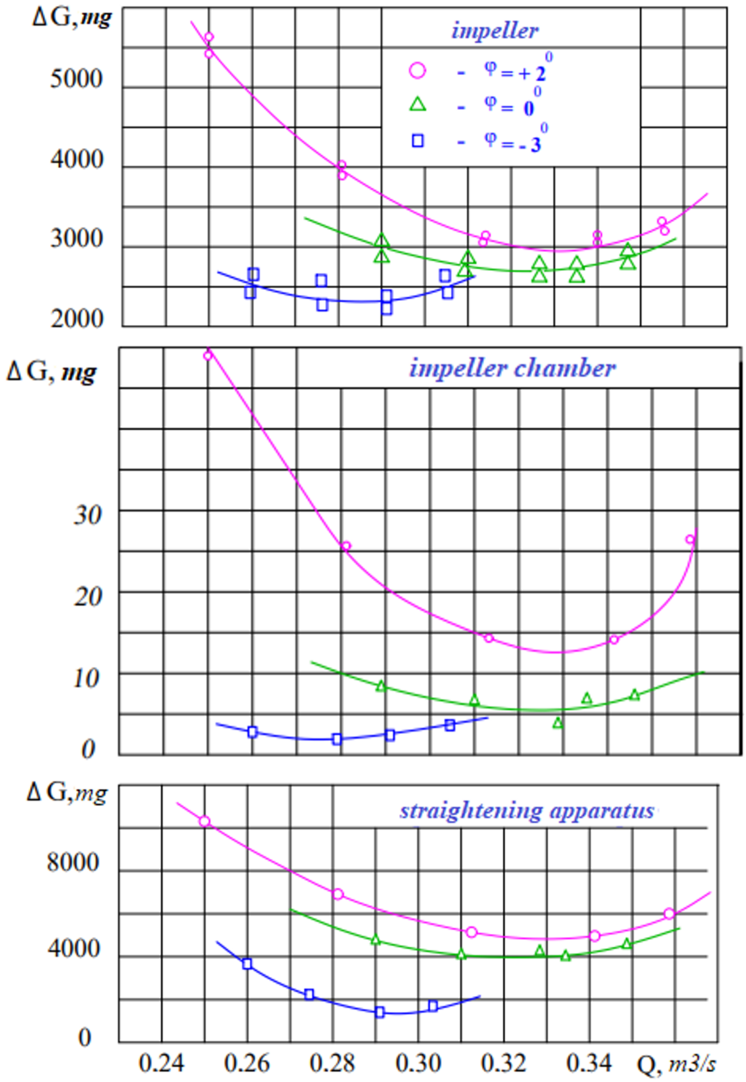


Fig. 3. Change in intensity of wear of parts of flow path depending on operating mode of axial pump at n_o = 960 rpm.

The given dependences (Fig. 4.) show that the wear of the end part does not depend on the nature of the flow around the blade with the working flow but depends on the speed of the hydroabrasive flow and the local concentration of sediments in the slot gap, which decrease with a decrease in the pump head.

As can be seen from Fig. 5, with an increase in the angle of installation of the blades φ in the mode $Q = Q_{exp}$, the wear ΔG increases, but the pump flow Q_{exp} also increases. The lowest wear intensity corresponds to the angles φ≤0˚. Therefore, the lowest relative wear of the impeller, reduced to a unit of delivery, can be obtained by operating the pump at an angle of installation of the blades φ≤0˚ in modes $Q=Q_{on}$. But the relative wear (ΔG/Q) of the impeller chamber and straightener reaches its minimum value only at small installation angles of the impeller blades (φ = -3˚) [11-14].

Experiments have established that an increase in the rotation frequency n_o leads to a more intensive increase in the wear of the straightening apparatus and the impeller chamber compared to the wear of the impeller. For example, at φ=0˚ with an increase in n_0 from 900 to 1020 rpm. Straightener wear has increased 3 times, while this ratio is only 1.3 for the impeller.

2 Research methodology

The main provisions of the theory of vane hydraulic machines and the theory of hydroabrasive and cavitation-abrasive wear of metals were used. Based on these theories, a method for calculating the intensity of hydroabrasive wear of the elements of the flow part of pumps is proposed. When conducting experimental studies, generally accepted standard laboratory and bench testing of pumps were used.

3 Results and Discussion

For a qualitative comparison of the forces acting on the walls of the chamber of the impeller, oscillography of pressure pulsations was carried out depending on the operating mode of the pump.

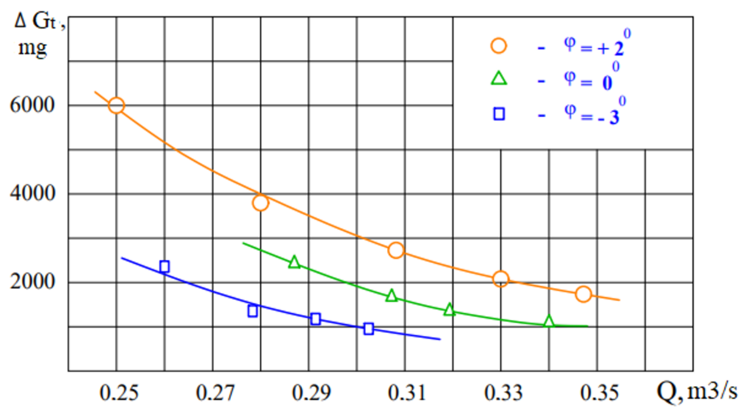
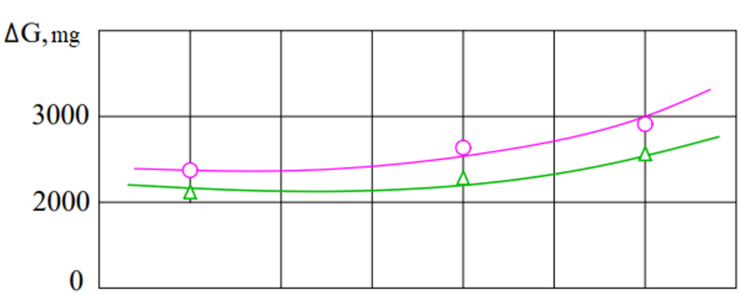


Fig. 4. Change in value of end wear of impeller blades depending on operating mode of axial pump at no=960 rpm.



a)

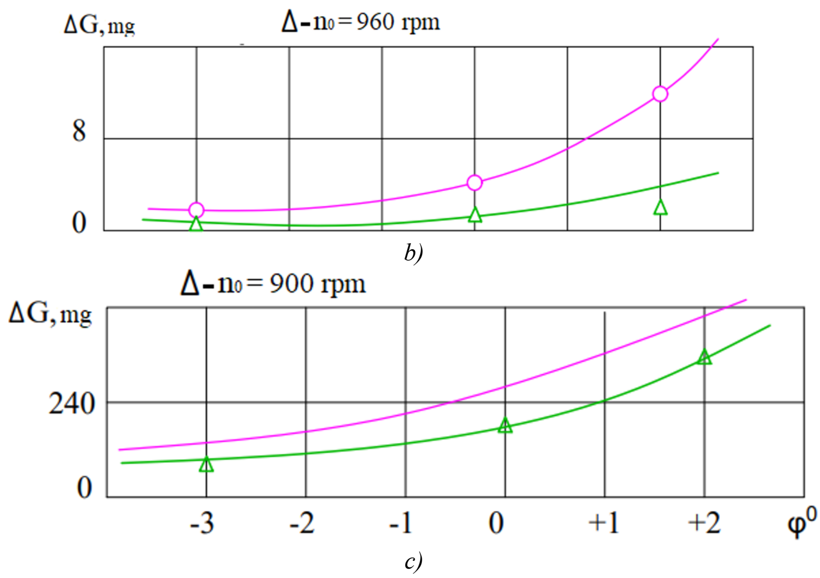


Fig. 5. Influence of installation angle of impeller blades on amount of hydroabrasive wear of parts of flow part of axial pump: a, b, and c, respectively, for impeller, chamber, and straightener.

The impeller for the sensor located at the level of the middle and final parts of the blade corresponds to the nature of the change in wear of the blades and the impeller chamber. The smallest pulsation value 2A', and the minimum wear value ΔG correspond to the $Q=Q_{exp}$ mode [15-22]. The correspondence between the nature of wear curves and pressure pulsations gives grounds to assert that the increase in the intensity of hydroabrasive wear is significantly affected by pressure pulsations that occur in the flow part of hydraulic machines, depending on their mode of operation. An increase in pressure pulsation in the flow leads to an increase in the level of turbulence and a change in the acceleration of solid particles and, accordingly, the force of their interaction with the surface of streamlined parts. All this leads to an increase in the intensity of wear of parts from the impact of solid abrasive particles.

To determine the angle of the interaction of solid particles with the blade's surface, special studies were carried out with samples of silumin balls, which are attached to the initial, middle, and final parts of the peripheral sections of the blades. The dependences of the angle α of the interaction of a solid particle with the surface of the blade on the operating mode of the pump are shown in Fig. 6. It shows that this angle α in the considered supply interval Q varies from 15˚ to 24.5˚. It should be noted that the angle α of particle interaction with the blade surface is always less than the angle of attack α_o of solid particles, determined by the wear angle of the blade's leading edge. The value of α is necessary for further analytical calculations using equations (1) and (3).

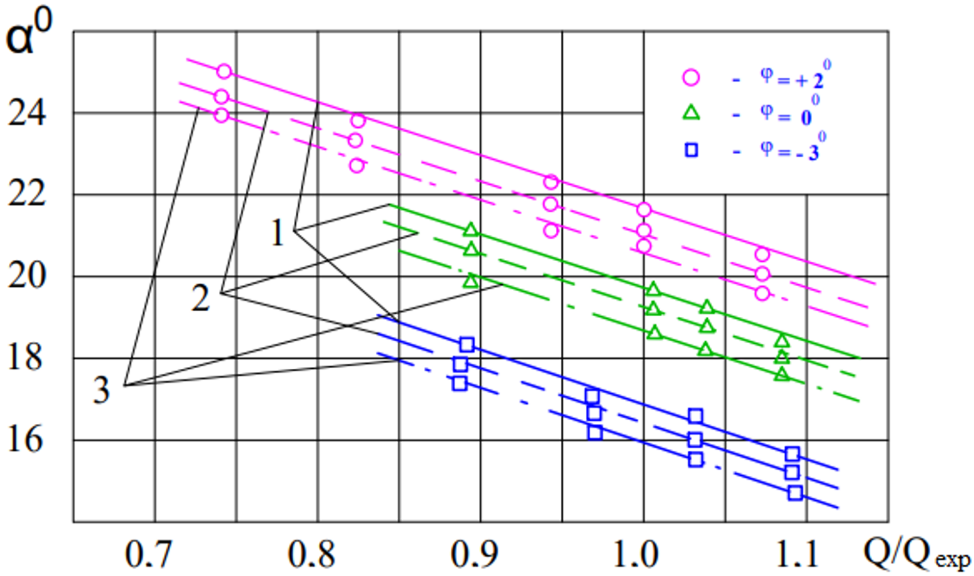


Fig. 6. Angle of interaction of solid particle with surface of blade, depending on mode of operation of axial pump at different angles of installation of blades φ: 1 is for initial section of blade, 2 is for middle part of blade, 3 is for end section of blade

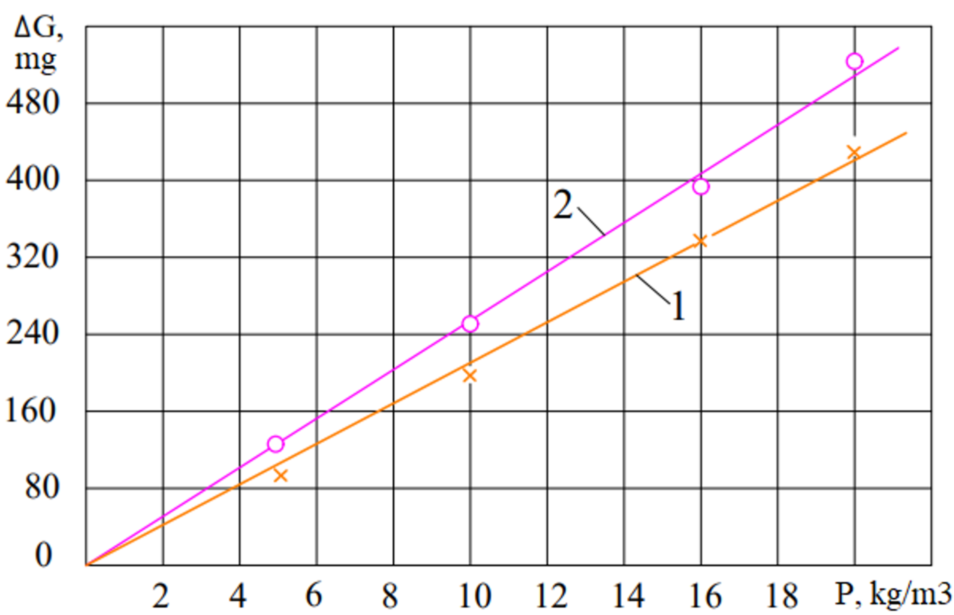


Fig. 7. Influence of sediment concentration on amount of hydroabrasive wear of centrifugal pump impeller: 1 $is\ for\ Q = 12\ l/s, 2\ is\ for\ Q = 16\ l/s$.

In axial pumps, the interblade channels communicate through the end clearance of the impeller. First, the resulting cavitation zones in the initial stages protect the blades' surface from the impact of solid particles in the same way as in centrifugal pumps. Secondly, due to the formation of cavitation zones in the pressure and vacuum end sections of the blade, the leakage of the hydroabrasive flow through the end gap decreases. Therefore, the change in the wear value ΔG of the impeller of an axial pump, depending on Δh, occurs more intensively than that of a centrifugal pump.

Experiments have shown that when changing the intensity of cavitation-abrasive wear of an axial pump, the installation angle of the impeller blades φ plays a significant role. The smaller the installation angle φ, the later the protective effect of cavitation appears. At a given speed, n_o=960 rpm. The strongest protective effect of cavitation zones appears at φ=+2°; it is weaker for φ=0° and does not appear at all for φ=-3°. For example, for φ=+2°, a decrease in Δh from 8.84 to 8.05 m leads to a decrease in hydroabrasive wear of the impeller by 24%, for φ=0° with a decrease in Δh from 8.5 to 7.74 m, there is a decrease in the intensity of hydroabrasive wear by only 17%, and for φ = -3° a decrease in Δh leads to a continuous increase in the intensity of wear of the pump impeller [6-8]. Based on the preceding, it is necessary to indicate that the greater the angle of installation of the impeller blades, the stronger the decrease in the intensity of hydroabrasive wear occurs with a decrease in Δh.

The studies carried out in various operating modes have shown that for axial pumps, the minimum values of the intensity of cavitation-abrasive wear of the impeller are near the stall zones of the cavitation characteristic in modes with $Q \geq Q_{exp}$ flow. According to the results of experimental studies, it should be noted that the presence of cavitation zones that occur with a decrease in cavitation reserve reduces the intensity of hydroabrasive wear of pump impellers in certain operating modes.

4 Conclusions

1. Based on the analysis of worn parts of pumps in laboratory conditions, a wear mechanism was chosen for the main parts of the flow path of axial and centrifugal pumps.
2. Analytical formulas have been derived to determine the amount of hydroabrasive wear of pump parts, taking into account the characteristics of the suspended flow, the properties of the wear material, and the operating modes of the pumps.
3. Experimental studies carried out on laboratory stands with axial and centrifugal pumps have obtained the dependences of wear on parts and the concentration and size of solid particles, duration of operation, rotational speed, angle of installation of the impeller blades, and operating modes of the pumps.
4. Laboratory studies make it possible to develop constructive protection measures and recommendations on the methodology for calculating the elements of sealing and slotted gaps of impellers of axial and centrifugal pumps.

References

1. Mamajonov, M., Bazarov, D. R., Uralov, B. R., Djumabaeva, G. U., & Rahmatov, N. The impact of hydro-wear parts of pumps for operational efficiency of the pumping station. In Journal of Physics: Conference Series, Vol. 1425, No. 1, p. 012123. IOP Publishing. (2019).
2. Uralov, B., Choriev, R., Maksudova, L., Sapaeva, M., Shernaev, A., & Nurmatov, P. Substantiation of the influence of the channel shape and the roughness of machine canals on the pressure loss of irrigation pumping stations. In IOP Conference Series: Materials Science and Engineering, Vol. 1030, No. 1, p. 012148. IOP Publishing. (2021).
3. Eshev, S., Gaimnazarov, I., Latipov, S., Mamatov, N., Sobirov, F., & Rayimova, I. The beginning of the movement of bottom sediments in an unsteady flow. In E3S Web of Conferences, Vol. 263, p. 02042. EDP Sciences. (2021).

4. Trulev, A., Verbitsky, V., Timushev, S., & Chaburko, P. Electrical submersible centrifugal pump units of the new generation for the operation of marginal and inactive wells with a high content of free gas and mechanical impurities. In IOP Conference Series: Materials Science and Engineering, Vol. 492, No. 1, p. 012041. IOP Publishing. (2019).
5. Akanova, G., Sładkowski, A., Podbolotov, S., Kolga, A., & Stolpovskikh, I. Ways to reduce hydraulic losses in multistage centrifugal pumping equipment for mining and oil-producing industries. Scientific Bulletin of National Mining University, (6). (2021).
6. Gülich, J. F. Centrifugal pumps, Vol. 2. Berlin: Springer. (2008).
7. Moloshnyi, O., Szulc, P., Moliński, G., Sapozhnikov, S., & Antonenko, S. The analysis of the performance of a sewage pump in terms of the wear of hydraulic components. In Journal of Physics: Conference Series, Vol. 1741, No. 1, p. 012015. IOP Publishing. (2021).
8. Shishlyannikov, D., Zvonarev, I., Rybin, A., Zverev, V., & Ivanchenko, A. Assessment of Changes in the Abrasiveness of Solid Particles in Hydraulic Mixtures Pumped with ESPs. Applied Sciences, 13(3), 1885. (2023).
9. Bazarov, D. R., Norkulov, B. E., Kurbanov, A. I., Jamolov, F. N., & Jumabayeva, G. U. Improving methods of increasing reliability without dam water intake. In AIP Conference Proceedings, Vol. 2612, No. 1. AIP Publishing. (2023).
10. Bazarov, D., Krutov, A., Sahakian, A., Vokhidov, O., Raimov, K., & Raimova, I. Numerical models to forecast water quality. In AIP Conference Proceedings, Vol. 2612, No. 1, p. 020001. AIP Publishing LLC. (2023).
11. Uralov, B., Mutalov, S., Shakirov, B., Khakimova, G., Sirojov, B., & Raimova, I. Influence of hydroabrasive wear of impeller blades on head of centrifugal pump. In E3S Web of Conferences, Vol. 365, p. 03012. EDP Sciences. (2023).
12. Burlachenko, A. V., Chernykh, O. N., Khanov, N. V., & Bazarov, D. R. Damping of increased turbulence beyond a deep and relatively short spillway basin. In AIP Conference Proceedings, Vol. 2612, No. 1. AIP Publishing. (2023).
13. Uralov, B., Berdiev, S., Rakhmatov, M., Vokhidov, O., Maksudova, L., & Raimova, I. Theoretical models and dependences for calculating intensity of hydroabrasive wear of pump working parts. In E3S Web of Conferences, Vol. 365, p. 03019. EDP Sciences. (2023).
14. Bazarov, D., Ahmadi, M., Ghayur, A., & Vokhidov, O. The Kabul River Basin-the source of the Naglu and other reservoirs. In E3S Web of Conferences, Vol. 365, p. 03047. EDP Sciences. (2023).
15. Kan, E. K. The method of hydroecological monitoring for hydropower and hydraulic facilities of the Kashkadarya region of Uzbekistan. In AIP Conference Proceedings, Vol. 2612, No. 1. AIP Publishing. (2023).
16. Kan, E., & Nasrulin, A. Technical and economic indicators of reconstructed irrigation pumping stations. In AIP Conference Proceedings, Vol. 2612, No. 1. AIP Publishing. (2023).
17. Kan, E., & Vatin, N. Consumption of Irrigation Pumps Pumping Water with a High Content of Mechanical Impurities. In E3S Web of Conferences (Vol. 365, p. 03011). EDP Sciences. (2023).
18. Bazarov, D., Vatin, N., Norkulov, B., Vokhidov, O., & Raimova, I. Mathematical Model of Deformation of the River Channel in the Area of the Damless Water

Intake. In Proceedings of MPCPE 2021: Selected Papers, pp. 1-15. Cham: Springer International Publishing. (2022).

19. Engel, R., Fibier, A., Heldt, J., & Ronecker, A. Hydro-Abrasive wear damage at reactor recirculation pump bearing journals. In Pressure Vessels and Piping Conference, Vol. 55065, pp. 137-144. American Society of Mechanical Engineers. (2012).
20. Höppel, H. W., Mughrabi, H., Sockel, H. G., Schmidt, S., & Vetter, G. Hydroabrasive wear behaviour and damage mechanisms of different hard coatings. Wear, 225, 1088-1099. (1999).
21. Norkulov, B. E., Nazaraliev, D. V., Kurbanov, A. I., Gayratov, S. S., & Shodiyev, B. Results of a study of severe deformation below the damless water intake section. In AIP Conference Proceedings,Vol. 2612, No. 1. AIP Publishing. (2023).
22. Norkulov, B., Khujakulov, R., Kurbanov, I., Kurbanov, A., Jumaboyeva, G., & Kurbanov, A. Regime of deposition of sediments in the head settlement basin of the supply channel of pumping stations. In E3S Web of Conferences, Vol. 365, p. 03045. EDP Sciences. (2023).