Detritus removal from a pumping-plant intake chamber with hydrajet pumps

M Muhammadiiev*, B Urishev, S Juraev, and A Boliev

1Tashkent State Technic University named after Islam Karimov, Department of power, Tashkent, Uzbekistan
2Karshi Engineering and Economics Institute, Karshi, Uzbekistan
3Jizzakh Politechnic Institute, Jizzakh, Uzbekistan

muhammadiev_m@rambler.ru

Abstract. Issues of excessive sedimentation of sediment in the pre-chambers of reclamation pumping stations are important in ensuring their reliable operation. Examinations have established that excessive detritus deposition in the intake part of the chamber complicates the water intake by pumps, increases energy consumption. For the timely cleaning of the intake chamber from detritus, a new device, equipped with a hydrajet pump fed from the pressure pipe of the main pump of the station is proposed. An equation for the pressure-flow characteristics of a water-jet pump used to drain the hydraulic mixture (water + solid mass) based on the of E.A. Sokolov and N.M. Singer methodology and the parameters of the hydrajet pump at given pressure values and the planned value of the flow rate of the solid mass have been obtained. The optimal values of the relative head $h = 0.19$ and the relative flow $q = 0.6$. At these values, the efficiency of the installation will be maximum. The results of the experiments carried out according to the estimation design have shown their satisfactory convergence with the calculated data and made possible to determine the optimal pressure and flow parameters of the hydrajet pump from the maximum efficiency.

1. Introduction

The value of reclamation pumping stations (PS) in the development of agriculture in the Republic of Uzbekistan is enormous, due to the fact that currently, of the 4.3 million hectares of irrigated land, 2.4 million hectares are provided with water supplied by pumping stations.

Due to the increased turbidity of the pumped water in many reclamation PS, the issues of timely cleaning of deposited detritus in water intake facilities are included in the category of important tasks. As the research results show, due to the uneven operation of the pumping units in time, and sometimes the imperfect design of the advance chambers, many PSs are silted [1,2,3]. The detritus deposited in a thick layer at the bottom of the structures violate the acceptable hydraulic flow structure, which negatively affects the operational parameters of the PS. At the same time, the annual cleaning of the water intake device and dash chambers from deposited detritus occupies a considerable share of operating costs, which creates additional problems and reduces the efficiency of the PS. Heavy equipment (excavators, bulldozers, dredgers) is used to clean the tank’s advance chamber, considerable labor force, the problem is aggravated by the fact that many detritus collectors have deposited thick layers of detritus by the middle of the growing season, which significantly complicate water intake by pumping units, especially extreme ones (fig. 1). According to [4], in the supply...
channels of the PS of the Amudarya basin, the detritus content varies from 2.8 kg/m³ to 12.8 kg/m³. In April, the content of suspended particles in the Kokayty PS in the Surkhandarya region of the Republic of Uzbekistan reaches up to 16.88 kg/m³ [5].

Detritus are the products of erosion of riverbeds, canals, and they are undesirable from the point of view of operating irrigation facilities [6]. In irrigation canals, they reduce the cross-section and throughput, which leads to a reduction in water supply; deposited in the upper pool of hydraulic structures above retaining dams, they change the design mode, increasing the water horizon above normal, and detritus deposition in reservoirs leads to a decrease in useful capacity, i.e. the volume of accumulated water. On the other hand, passing small fractions of suspended particles into irrigated fields that contain a large number of minerals contributes to an increase in soil fertility [7].

The purpose and objectives of the research are to analyze existing methods for preventing silting of pumping stations' chambers, to study the possibilities of using a water jet installation and methods for determining its optimal parameters based on field experiments.

Cleaning the tank chambers from detritus deposits is a time-consuming process, usually, this work is carried out during periods of stopping and repairing the PS using earthmoving equipment after drainage the tank chamber. There are other methods for removing detritus from the bottom of the tank chamber during the period of operation of the National Assembly, for example, dredgers, mud pumps, soil sampling ejectors that receive water from special pumps. These methods are not widely used due to significant capital and operating costs.
In order to reduce capital and energy costs when cleaning chambers from detritus, a new design of a water intake structure with a device containing a water-jet pump was proposed [8] (Fig. 2.).

![Figure 2. New design of the water intake structure with a device for cleaning detritus in chambers](image)

1 is absorption pipe of the pump; 2 is pump; 3 is ejector; 4 is pressure pipeline; 5 is pipe for supplying the working stream to the ejector; 6 is flexible pipe; 7 is hydraulic ripper; 8 is slurry pipeline; 9 is service bridge.

A distinctive feature of this device is that part of the water pumped by the main pumping unit of the station is used to power the hydra jet pump. This approach allows you to provide a water-jet pump with a working stream of water from the main pressure pipe instead of a special pump installation, which is usually used for this purpose. This significantly reduces the cost of detritus removal from the chamber of the pumping station.

The proposed device operates as follows. When cleaning the dampers, the chambers supply water under pressure from the pressure line 4 of the main pump 2 to the hydrajet pump 3, as a result of which a pressure drop is formed in it, which ensures the suction of the hydraulic mixture (water and detritus) from the bottom of the ditch chamber. The hydraulic mixture injected by the working stream of water from the supply pipe 5 is fed into the slurry pipe 8 for the removal of detritus to a specially designated place. Loosening (stirring) detritus deposition is carried out by a hydrocracker 7, made in the form of an annular perforated pipe. If necessary, the flexible (corrugated) part 6 of the inlet pipe 5 and the bridge 9 provides a change in the location of the hydrajet pump 3. This device allows you to clean up the chambers during operation of the pump station without stopping the units.

Hydra jet pumps (HJP) are used in a variety of technological processes. Their widespread use is due to the simplicity of design and manufacturing techniques, small dimensions and weight, the absence of mobile working bodies, and reliable operation [9]. These advantages, despite the very low efficiency (up to 30%), provided them with applications in various fields of technology, including the hydrotransport of solid mass and suspensions of various concentrations.

For many years, the American company JJ Tech has successfully used HJP to extract oil and gas and other products from wells [10]. HJP are used for technical water supply to hydroelectric power stations, pumping water from various reservoirs, and transporting suspensions, pulp with particulate matter [9][11][12].

A large number of published works are devoted to questions of research and calculation of HJP, which investigated possible operating modes, parameters, varieties of inkjet devices in various operating conditions. Despite the limitations of the publication of these works, even today they have not lost their value and interest for design engineers, as well as for new research using GOS. Let us dwell on some of them, mainly on studies with the transportation of slurry, which is typical for detritus in the fore tanks of PS (sand + clay + water).
In [13], the authors proposed an equation for the pressure-flow rate characteristics of the HJP, characterized in that it takes into account the effect of the sliding of a solid mass particle on the flow rate. This fact affects the pump capacity for solid mass.

In [14], the results of theoretical and experimental studies for the transportation of solid materials are presented, and, on their basis, a method for determining the performance of HJP is proposed.

The authors of [15], based on theoretical and experimental studies, found that the maximum efficiency of the HJP is achieved when the ratio of the area of the exit section of the nozzle to the sectional area of the displacement chamber \( \bar{\theta} = 0.26 \). A result close to this (\( \bar{\theta} = 0.25 \)) was found in the studies described in [16]. Almost the same results (\( \bar{\theta} = 0.22 \) at a relative flow rate of \( q = 1.0 \) suspension) were obtained in [17].

In [18], HJP with venturi-type ejectors was studied, and based on the results obtained, the authors proposed the optimal geometric dimensions of the ejector, which made it possible to improve the HJP performance at \( \bar{\theta} = 0.35 \) in 30.5%.

In [19], a technique was presented for developing a hydrodynamic model of a turbulent flow in a HJP. On this model, numerical studies of the influence of geometric parameters on pump performance were performed using the CFD platform and the least-squares method, the results of which showed the possibility of increasing the pump efficiency up to 33% and reducing the power consumption of the pump by more than 20%.

2. Methods

The research methodology includes an analysis of existing methods for preventing the siltation of the pre-chamber using water-jet installations, analytical development of the theory of E.A. Sokolov and N.M. Singer based on the results of field experiments of a water-jet installation.

Evaluation of the operation of the device shown in Fig. 2 can be made based on the analysis of the following main technological parameters:

- a) head \( H_1 \) and flow rate \( Q_1 \) of the working water flow;
- b) the consumption of hydraulic mixtures (water + detritus) \( Q_2 \);
- c) the pressure at the outlet of the H_1 water-jet pump;
- g) detritus flow rate \( Q_m \);
- e) the geometric dimensions of the hydrajet pump;

There are several methods for calculating the above parameters, which are based on the use of the equation of momentum and force momenta when two flows are displaced, compiled for the fluid compartment between the initial and final sections of the displacement chamber and basically differ from each other in the completeness of energy losses [9, 11, 12, 13].

The pressure and flow characteristics (PFCH) of a water-jet pump, most researchers present in the form of graphical dependencies in the form \( h = f(q) \), where \( h \) is the relative pressure determined by the following formula

\[
h = \frac{H_3 - H_2}{H_1 - H_2}
\]

(1)

\( q \) is relative flow rate of the HJP;

\[
q = \frac{Q_2}{Q_1}
\]

(2)
The most developed and common methodology for determining the PFCH of HJP for transporting solid mass is the method E.A. Sokolov and N.M. Singer [20]. Using this technique, it is proposed to determine the function \( h = f(qt) \) by the following equation

\[
h = \frac{2\varphi_2 + \left(2\varphi_2 - \frac{1}{\varphi_1^2}\right)MQ_{12}^2(l+\alpha_2)}{\left[(2-\varphi_2^2)\varphi_1^2[l+q_m(l+\alpha)] + \frac{\rho_2}{\rho_3}q_m^2\right]}
\]

where \( \varphi_1, \varphi_2 \) is the nozzle exit section area, \( \varphi_2 \) is the cross-sectional area of the displacement chamber, \( S = l/(1-\varphi_1) \), \( \alpha = Q_3/Q_m \), \( Q_m \) is the flow rate of solid mass (detritus), \( q_m = Q_m/Q_t \) is relative detritus discharge, \( \varphi_1, \varphi_2, \varphi_3, \varphi_4 \) are velocity coefficients of the nozzle, displacement chamber, diffuser and entrance to the displacement chamber, the values of which are determined as follows: \( \varphi_1 = 0.95, \varphi_2 = 0.875, \varphi_3 = 0.81, \varphi_4 = 0.83 \) [20].

Given the above coefficients, equation (9) takes the following form

\[
h = 0.902MQ_{12}^2(l+\alpha_2) \left\{ \frac{\rho_2}{\rho_3}q_m^2 \right\}
\]

The optimal ratio of the sections \( \varphi \), using the above methodology, is determined by the following dependence

\[
\varphi = \frac{h}{\varphi_1^2 \cdot \varphi_2^2}
\]

where \( h \) is determined by the formula (1) with known values of \( H_1, H_2, \) and \( H_3 \).

Thus, for the given values of the flow proportions \( \alpha \) and the known \( \rho_1, \rho_2, \rho_3, \rho_m \), according to formula (3a), one can find the PFCH of the HJP, designed for detritus removal with a relative flow rate \( q_m \), which is expressed by a power equation of the type

Figure 1. The main hydraulic parameters of the hydrajet pump
1 is absorption confuser; 2 is nozzle; 3 is displacement camera; 4 is diffuser; 5 is slurry pipeline.
where A, B, and C are the coefficients.

The efficiency of the HJP on the supply of solid mass can be determined depending on the dimensionless quantities \( q_m \) and \( h \) by the following expression

\[
\eta = q_m h / (1 - h)
\]

3. Results

According to the calculation results obtained under conditions corresponding to \( H_1 = 40 \) m, \( H_2 = 3.0 \) m, \( H_3 = 10 \) m, \( \alpha = 1.0; \rho_1 = \rho_2 = 1000 \) kg/m\(^3\); \( \rho_2 = 1500 \) kg/m\(^3\); \( \rho_m = 2250 \) kg/m\(^3\) the equation characterizing the PFCH of the HJP for the removal of solid mass (sand + clay) will take the following form

\[
h = 0.344 - 0.184 \cdot q_m - 0.101 \cdot q_m^2
\]

The PFCH graph of the HJP constructed according to (7) is presented in Fig. 4.

By the characteristic \( h = f(q) \), the quantity \( q_m \) is determined, then, with the planned value of \( Q_m \) it is possible to calculate the flow rate of water \( Q_1 \), supplied to the nozzle from the pressure pipe.

The area of the outlet cross-section and, accordingly, the nozzle diameter are determined by the following relationships

\[
\omega_1 = 0.238 \frac{Q_1}{\sqrt{H_1}} \quad \text{(at } \varphi_1 = 0.95); \quad d_n = 1.13 \sqrt{\omega_2}
\]

Similarly, the cross-sectional area is calculated by \( \omega_2 = \omega_1 / \varphi_1 \) and the diameter of the displacement chamber according to the formula.

![Figure 2](image)

**Figure 2.** Pressure-flow characteristic of a hydraljet pump pumping a solid mass (detritus): --- is calculated curve according to (6); _ _ _ _ _ is experimental data curve; ……… is pump efficiency curve.

4. Discussions

Experimental studies were carried out in compliance with the conditions adopted in the above calculations and the nozzle diameter was \( d_n = 0.015 \) m, and the diameter of the displacement chamber was \( d_{dc} = 0.030 \) m, the length of the displacement chamber was \( l_{dc} = 0.25 \) m, the detritus discharge was adopted \( Q_m = 3.0 \) l/s.

The experimental results are presented in figure 3 and they have close values to the calculated ones and on this basis it can be assumed that the above methodology can be used to approximate the determination of HJP parameters. According to the results of the experiments, the optimal values of the relative pressure \( h \) and flow rate \( q \), corresponding to the maximum efficiency of the seeker (\( h = 0.19, q = 0.6 \)), were determined.

5. Conclusions
1. The methodology for determining the pressure-flow rate characteristics of a hydrajet pump designed to discharge detritus from the fore chamber of pumping stations has been improved.

2. The equation of the pressure-flow rate characteristics of the hydrajet pump is proposed and the calculated data on the specific conditions of the supply of the working stream and detritus discharge is obtained.

3. Experimental studies were carried out under the conditions adopted in the calculations and the obtained experimental results are close to the calculated values.

4. The optimal values of h and q corresponding to the maximum efficiency of the water-jet pump were determined.

6. Acknowledgments
The authors are deeply grateful to the Amu-Kashkadarya Basin Administration of Irrigation Systems for the information provided in the preparation of this work.

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