A new technology in cleaning irrigation systems from turbid sediments

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Abstract. The current article considers a method of improvement based on the laws of flow motion in developing resource-saving devices based on the analytical analysis of research on using air ejectors in the national economy. The hydraulic parameters of the jet lift and air ejector are theoretically based, and the connections obtained are tested experimentally. Based on the experiments, the economical parameters of the inlet water lift and air ejector were determined. It was determined that the working pressure of the laboratory water intake device for taking water from a well at a depth of 1 m to a height of 2 m is H_i = 1 m, working flow consumption Q=29.52·10-5 m^3/s. Based on theoretical research and experimental data, the consumption characteristics of the structured water lift and air ejector were constructed.

1 Introduction

One of the most important issues in the world is the creation of methods to clean the hydraulic structures of reservoirs, diversions used for various purposes, and irrigation systems and prevent their turbidity, to maintain the useful volume of water bodies. In this regard, creating a device for trancmitting three-phase flow in the form of hydromechanization, consisting of solid particles (turbid sediments) and a contiguous medium that transports them is especially important. In this regard, special attention is paid to ensuring the efficient use and safety of hydraulic structures and irrigation systems and increasing their useful capacity in the United States, the Netherlands, Russia, China, South Korea, and other developed countries.

One of the most pressing issues today is introducing innovative methods in water production, first of all, modern water and resource-saving technologies, the use of high-efficiency agricultural machinery and technology [1]. There are several developments in this area; the main issue in developing the theoretical basis of water trancmission and lifting devices, as well as improving the operating mode, is to increase the efficiency of water lifts [2,3]. Based on the above, this article presents methods for calculating the resource-saving design parameters of a structured water lift. The existing calculation methods show that the substantiation of the parameters of structural water lifts should be based on the laws of flow movement [4]. In this case, the main problem is carrying more water with less energy.

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Today, there are relatively muddy suction devices that clean irrigation systems from muddy sediments, are cost-effective, and have relatively low metal and energy consumption. They allow the absorption of turbid sediments from a depth of up to 30 m.

The main advantages of easy-to-assemble mud turbines are energy saving, high reliability, quickly absorbing and dicmantling water and turbid mixtures, and moving the device from one work site to another.

The degree to which the issue has been studied. To develop the theory of hydromechanization of irrigation systems, N.D. Xolin, N.V. Melnikov, G.A. Nurok, I.M. Yaltanets, E.A. Kononenko, G.A. Abramovich, G.N. Roer, G.P. Nikonov, S.S. Shavlovskiy, V.F. Xnykii, S.B. Fogelson, N.A. Lopatin, B.A. Volnin and many other scientists are the ones who have made great contributions of their own. In their scientific research, they recommended various constructions of turbid sediment treatment technology. But in their proposed technology considers two-phase (water and turbid) flow motion. The main working fluid was used as water. Scientific research has shown that the technologies used so far have the following shortcomings.

- Corrosion of the suction line and the pump impeller is observed during pumping water and sludge.

-The occurrence of cavitation in the pump working chamber increases, resulting in eroding the working wheel and the working chamber.

-when sucking water and sludge, sludge particles hit the pump impeller at high speed and cause abrasive erosion.

-Currently used turbid suction devices weigh about 100 tons. Moving them from one object to another takes time and money.

2 Materials and Methods

In substantiating the design parameters of the air ejector, it is necessary to evaluate the hydraulic processes of the air flow in the working chamber (Figure 1).
In this type of fuzzy suction air ejectors, hydraulic resistance and energy losses are lower than water lifting device devices [5,6], resulting in higher operating efficiency of water lifting compared to water-powered devices [7].

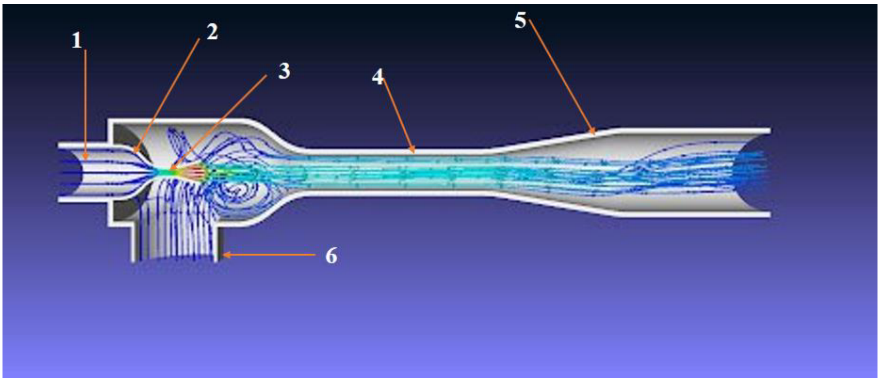

Fig. 1. Schematic of an air ejector device: 1 is working air duct; 2 is active tube (nozzle); 3 is transition section; 4 is mixing chamber of currents; 5 is diffuser; 6 is water supply pipe

The working pressure for the given air ejector circuit is the source that starts the air ejector device, determined based on the difference between the pressure at the inlet (1-1) and outlet (2-2) of the working chamber [8, 9]:

$$H_p = \frac{p_1}{\gamma} + \frac{\upsilon_1^2}{2g} - \frac{p_2}{\gamma} - \frac{\upsilon_2^2}{2g} \tag{1}$$

here: $\frac{p_1}{\gamma}, \frac{p_2}{\gamma}$ are pesometric heights in sections 1-1 and 2-2, respectively; $\frac{\upsilon_1^2}{2g}, \frac{\upsilon_2^2}{2g}$ are speed gauges in sections 1-1 and 2-2, respectively;

The pressure created in the air ejector is called the working pressure, and it is defined as follows:

$$H_p = \frac{p_1}{\gamma} + \frac{\upsilon_1^2}{2g} - \frac{p_2}{\gamma} - \frac{\upsilon_2^2}{2g} \tag{1a}$$

The process air flow in the air ejector is called the working air flow and is determined based on the following scheme:

$$Q_1 = \vartheta_1 \cdot \omega_1 = \vartheta_1 \cdot \frac{\pi}{4} \cdot d^2 \tag{2}$$

where ϑ_1 is the flow rate from the air ejector tube, d is the diameter of the tube's outlet. The air flow in the air ejector is determined as follows:

$$Q_3 = \vartheta_3 \cdot \omega_3 = \vartheta_3 \cdot \frac{\pi(d_0{}^2 - d^2)}{2} \tag{2a}$$

where ϑ_3 is flow rate at the outlet of the diffuser, d_0 is diameter of the mixing chamber of the currents.

The flow losses occur during the joining processes of the streams, due to friction in the walls of the working part of the water lift and as a result of reducing the flow's kinetic energy (in the diffuser) [10,11].

A device model has been developed to test the operation of the air ejector in the laboratory. In the process study based on the modeling requirements, the basic parameters are written in the form without units of measurement [12,13]. Listed above (1-4) Solve the system of equations together to obtain convenient expressions for analysis.

Relative pressure:

$$H = \frac{H_k}{H_k + H_p} \tag{3}$$

Relative consumption (injection coefficient):

$$H = \frac{Q_3}{Q_1} \tag{4}$$

Laboratory studies are required to determine the optimal values of the above parameters [14, 15]. Based on theoretical research, the initial parameters of the flow are determined to evaluate the operating mode in the air ejector. Using an air ejector, draw water from a depth of H_1=11 cm. It is necessary to determine the initial pressure and working current consumption, which must be trancmitted to a height of $H_2 = 0.6$ cm. Laboratory studies have examined the air trancmission capabilities of an air ejector

Parameters of the air ejector for laboratory research: the diameter of the working tube d_0= 2 mm, the diameter of the mixing chamber d_1= 10 mm, the diffuser diameter d_2= 20 mm were adopted.

Problem statement. In the study, the flow rate trancmitted through the air ejector and the flow coefficient of the pipe are studied depending on some criterion parameters. The flow rate from the propeller pipe of the air ejector is one of the most important parameters in determining the hydraulic elements of the system. Therefore, the research aims to study the hydraulic calculation of the flow in the pipe.

3 Results and Discussion

In theoretical research, we use an equation representing the energy state of the flow to evaluate the hydraulic processes in the mixing chamber. Based on the conditions of the problem, we adopt the following calculation scheme (Figure 2). Then D. Bernoulli's equation for sections 1-1 and 2-2 is written as follows:

$$\frac{H_1}{\gamma}+\frac{\vartheta_1^2}{2g}=H_2+\frac{(\vartheta_1-\vartheta_2)^2}{2g}+\xi_g\frac{(\vartheta_2-\vartheta_3)^2}{2g}+\xi_2\frac{\vartheta_3^{\,2}}{2g} \quad (5)$$

where ϑ_1 is flow rate from the air ejector tube; ϑ_2 is flow rate in the mixing chamber; ϑ_3 is flow rate at the outlet of the diffuser; ξ_g is diffuser resistance coefficient; ξ_2 is output resistance coefficient.

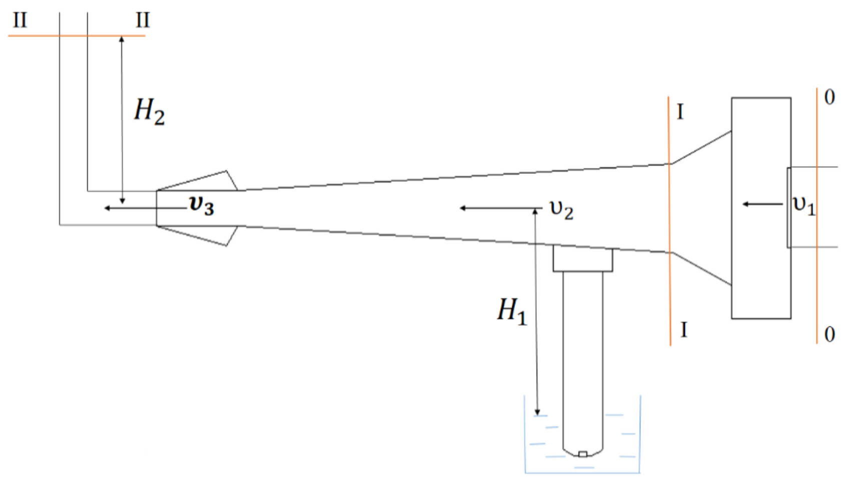

Fig. 2. Calculation scheme of the air ejector.

In the initial case, using the pressure in the section $P_1= \gamma H_1$ and the continuity equation $\omega_1\vartheta_1=\omega_2\vartheta_2=\omega_3\vartheta_3$, expression (2) is written as [16, 17]:

$$-H_1+\frac{\vartheta_1^2}{2g}=H_2+\frac{\left(\vartheta_1-\frac{\omega_1}{\omega_2}\vartheta_1\right)^2}{2g}+\xi_g\frac{\left(\frac{\omega_1}{\omega_2}\vartheta_1-\frac{\omega_1}{\omega_3}\vartheta_1\right)^2}{2g}+\xi_2\frac{\left(\frac{\omega_1}{\omega_3}\right)^2\vartheta_1^{\,2}}{2g} \quad (6)$$

Pour the air ejector parameters into the given expression:

$$\frac{\vartheta_1^2}{2g}=H_1+H_2+\frac{\left(1-\frac{d_0^{\,2}}{d_1^{\,2}}\right)^2\vartheta_1^2}{2g}+\xi_g\frac{\left(\frac{d_0^{\,2}}{d_1^{\,2}}-\frac{d_0^{\,2}}{d_2^{\,2}}\right)^2\vartheta_1^2}{2g}+\xi_2\frac{\left(\frac{d_0^{\,2}}{d_2^{\,2}}\right)^2\vartheta_1^{\,2}}{2g} \qquad (7)$$

The following expression is written for the flow rate out of the tube:

$$\vartheta_1=\sqrt{\frac{2g(H_1+H_2)}{1-\left(1-\frac{d_0^{\,2}}{d_1^{\,2}}\right)^2+\xi_g\left(\frac{d_0^{\,2}}{d_1^{\,2}}-\frac{d_0^{\,2}}{d_2^{\,2}}\right)^2+\xi_2\left(\frac{d_0^{\,2}}{d_2^{\,2}}\right)^2}} \qquad (8)$$

For an air ejector device under laboratory conditions, the water flow out of the tube is determined using expression (5):

$$Q=\omega_1\vartheta_1=1.52\ \text{cm}^3/\text{s} \qquad (9)$$

where: ϑ_1 is flow rate exiting the air ejector tube, ω_1 is air ejector tube surface.

The working pressure required to start the air ejector is determined based on the parameters set. In this case, the pressure in the working flow pipe of the air ejector is determined:
for this, the Bernoulli equation is written for the 0-0 and 1-1 cuts:

$$Z_0+\frac{P_0}{\gamma}+\frac{\alpha_0\vartheta_0^2}{2g}=Z_1+\frac{P_1}{\gamma}+\frac{\alpha_1\vartheta_1^2}{2g}+h_{0-1} \qquad (9a)$$

where: ϑ_0 is velocity of the working flow in the pipe; h_{0-1} is 0 and lost pressure between cuts 1-1;

Given the cmall distance between sections 0-0 and 1-1 in the device under consideration, h_{0-1} is determined as follows:

$$h_{0-1}=\xi_c\frac{\vartheta_1^{\,2}}{2g} \qquad (10)$$

where: ξ_c is coefficient of resistance of the tube;

Depending on the mode of motion as turbulent, it is assumed to be equal to $\alpha_0\approx\alpha_1\approx1$ [18-20].

As a result, the minimum working pressure is determined to start the transfer of water through the air ejector:

$$\frac{P_0}{\gamma}=-H_1-\frac{\alpha_0\vartheta_0^2}{2g}+\frac{\alpha_1\vartheta_1^2}{2g}+h_{0-1}=-1-\frac{\alpha_0\vartheta_0^2}{2g}+\frac{\alpha_1\vartheta_1^2}{2g}+h_{0-1} \qquad (11)$$

Based on the parameters identified in the theoretical studies, studies were conducted in the laboratory to determine the operating modes of the Struya water intake (Table 1, Figure 3) and air ejector (Table 2, Figure 4). In these studies, a graph of the dependence of the trancmitted water consumption on the working pressure was constructed (Figures 3 and 4).

Table 1. Laboratory research schedule.
(when the working fluid is selected as water and researched)

№	H_p, cm	Q_p, cm^3/s	H_1 , cm	Q_1, cm^3/s	Q_0, cm^3/s	ΔH,	q
1	150	386	70	51	437	0.467	0.132
2	200	397	70	103	500	0.35	0.259
3	250	443	70	140	583	0.28	0.316
4	300	470	70	158	628	0.233	0.336
5	350	507	70	193	700	0.2	0.381
6	400	617	70	258	875	0.175	0.418
7	500	700	70	294	994	0.14	0.42
8	550	809	70	357	1166	0.127	0.441
9	650	890	70	470	1360	0.108	0.528

Note: ΔH is relative rate, q is Relative consumption (injection coefficient), H_p is working rate, H_1 is lifting height, Q_p is unwanted consumption, Q_1 is additional consumption, Q_0 is total consumption.

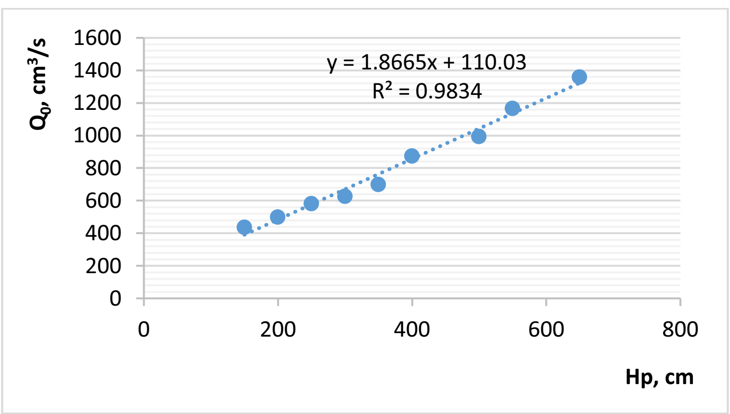

Fig. 3. Graph of water consumption dependence on working pressure

Theoretical research and analysis of laboratory data based on mathematical, and statistical methods to obtain a link between the consumption and pressure of the structured lift.

Table 2. Laboratory research schedule (research conducted by air ejector)

№	t, c	V (cm^3)	Q (cm^3/s)	d. mm	H_1 cm
1	10.84	14.09	1.299	2	4.2
2	11.36	15.11	1.33	2	6.2
3	12.01	17.54	1.46	4	9.1
4	12.82	19.05	1.485	4	10.1
5	12.46	18.42	1.478	6	10.5
6	11.46	17.43	1.52	6	11.5

Note: *t* is time, *V* is volume, d is suction pipe diameter, H_1 is lifting height, *Q* is total consumption

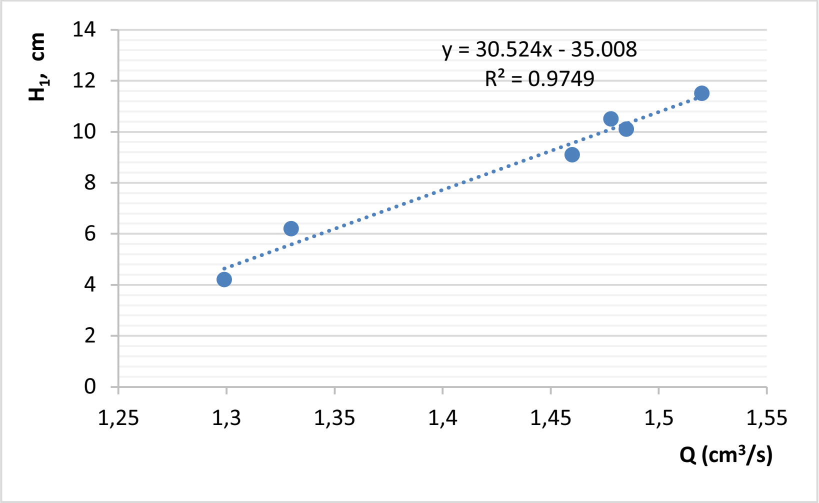

Fig. 4. Consumption-dependent graph of suction depth

The relationship between the consumption and pressure of the air ejector is obtained by analyzing the data obtained in the laboratory based on mathematical and statistical methods.

4 Conclusion

The article considers a method of improvement based on the laws of flow movement in the development of resource-saving devices based on the analytical analysis of research on the use of structured lifts and air ejectors in the national economy. The hydraulic parameters of the jet water lift and air ejector are theoretically based, and the obtained connections are tested experimentally. Based on the experiments, the parameters of the injector lift and air ejector were determined.

Based on theoretical research, it can be concluded that a laboratory water pumping device takes water from a well at a depth of 1 m and transfers it to a height of 2 m to the worker energy H_i=1 m worker flow consumption is Q=29.52 $\cdot 10^{-5}$ m^3/s. From a depth of $H_1 = 11$ cm, the initial pressure at which the water should be transferred to a height of $H_2 = 0.6\ cm$, and the working flow rate was determined to be Q = 15.2 cm^3/s. Laboratory studies have determined the amount of water and air transfer at different pressures of the injector water intake and air ejector. Based on theoretical research and experimental data, the consumption characteristics of the pumped water lift and air ejector were constructed.

The studies determined the relationship between the length of the mixed chamber and the diameter of the pipe. Comparing the values of the calculated and theoretical consumption, the optimal dimensions of the injector lift and air ejector were recommended. In the future, it will be possible to use air ejectors to clean turbid sediments in irrigation systems.

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