

Investigation of the influence of geometric parameters of a multi-nozzle jet pump on its energy characteristics

V Chermushkin^{1,2} and A Polyakov¹

¹Bauman Moscow State Technical University

²E-mail: vcheremushkin@bmstu.ru

Abstract. In this paper the optimization process of a jet pump developed according to a multi-nozzle scheme and designed to pump a mixture of water and soil is considered. Its flow part was designed, some measures were taken to accelerate the calculation process, including a method of setting the boundary conditions. Criteria and optimization parameters, the mathematical model used are given in the text. According to the calculation results, the best models and some dependencies of the criteria on the varied parameters are shown. The flow patterns in the flow part of the jet pump are presented.

Introduction

A jet pump is a device for pumping liquid due to the work performed by the flow of a liquid. Figure 1 shows a schematic diagram of a jet pump.

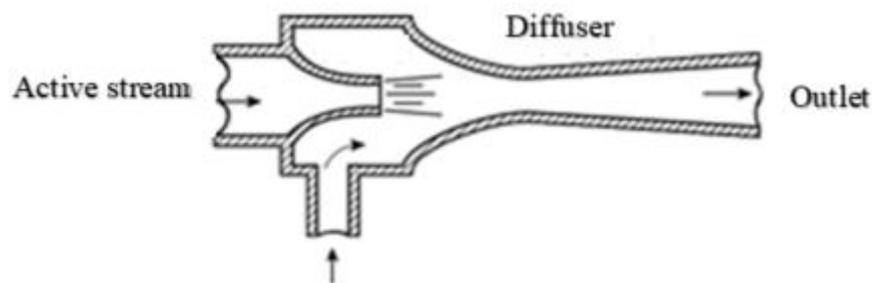


Figure1. Schematic diagram of a jet pump

Regardless of the design of the jet pump, it always directly transfers energy from a flow of a liquid to the flow of the ejected liquid. The first stream is active, and the second one is passive [1].

The necessary elements for the implementation of the jet pump workflow are the supply nozzles of the active and passive flows, the mixing chamber and the outlet diffuser.

Jet pumps are widespread in many areas of industry. Such qualities as high reliability associated with the absence of moving elements, the ability to work with aggressive liquids containing gas and solid inclusions greatly facilitated that. The resource of jet pumps is limited only by the properties of the materials that were used for its manufacture.

This article discusses the issue of optimizing the energy characteristics of a jet pump developed according to a multi-nozzle scheme with a peripheral disposition of active flow nozzles.

Such a constructive decision was made according to the tasks that were faced in the process of development. A feature of the pumped medium is the presence of solid inclusions. These factors make it impossible to rely on existing works on the optimization of classical jet pumps [2–4].

Mathematical Model and Methods

The task of designing the diverting device is solved by means of CFD (computational fluid dynamics). The implementation of the numerical simulation method is based on solving the basic hydrodynamic equations discrete analogs [5–8]. In case of an incompressible fluid model, when the density is constant, these are:

Continuity Equation

$$\frac{\partial \tilde{u}_j}{\partial x_j} = 0,$$

where \tilde{u}_j — j axis projection of an averaged value of the fluid velocity ($j=1,2,3$);

The momentum conservation equation (Reynolds averaged):

$$\rho \left[\frac{\partial U_i}{\partial t} + U_j \frac{\partial U_i}{\partial x_j} \right] = - \frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_i} \left[\tilde{T}_{ij}^{(v)} - \rho u_i u_j \right];$$

where U, P — averaged velocity and pressure;

$\tilde{T}_{ij}^{(v)} = 2\mu\tilde{s}_{ij}$ — viscous stress tensor for incompressible fluid;

$\tilde{s}_{ij} = \frac{1}{2} \left[\frac{\partial \tilde{u}_i}{\partial x_j} + \frac{\partial \tilde{u}_j}{\partial x_i} \right]$ — instant strain rate tensor;

$\rho u_i u_j$ — Reynolds stresses.

The introduction of the Reynolds averaged Navier-Stokes equation makes the equations system not closed, as additional unknowns, Reynolds stresses, appear.

To solve this system of equation, the k - ω SST turbulence model was used. It introduces the necessary additional equations: the transport equations for the turbulent kinetic energy and the relative dissipation rate of this energy:

$$\frac{\partial k}{\partial t} + U_j \frac{\partial k}{\partial x_j} = P_k - \beta^* k \omega + \frac{\partial}{\partial x_j} \left[(v + \sigma_k v_T) \cdot \frac{\partial k}{\partial x_j} \right]$$

$$\frac{\partial \omega}{\partial t} + U_j \frac{\partial \omega}{\partial x_j} = \alpha \cdot S^2 - \beta \cdot \omega^2 + \frac{\partial}{\partial x_j} \left[(v + \sigma_\omega v_T) \cdot \frac{\partial \omega}{\partial x_j} \right] + 2 \cdot (1 - F_1) \cdot \sigma_{\omega 2} \cdot \frac{1}{\omega} \cdot \frac{\partial k}{\partial x_i} \cdot \frac{\partial \omega}{\partial x_i}$$

When searching for the values of the optimal geometric parameters of the elements of the jet pump, a combination of stochastic and local (directional) search was used [9].

Figure 2 shows the computational grid used in hydro modeling. The grid has polyhedral cells inside the flow in the flow core and prismatic near lid walls [10].

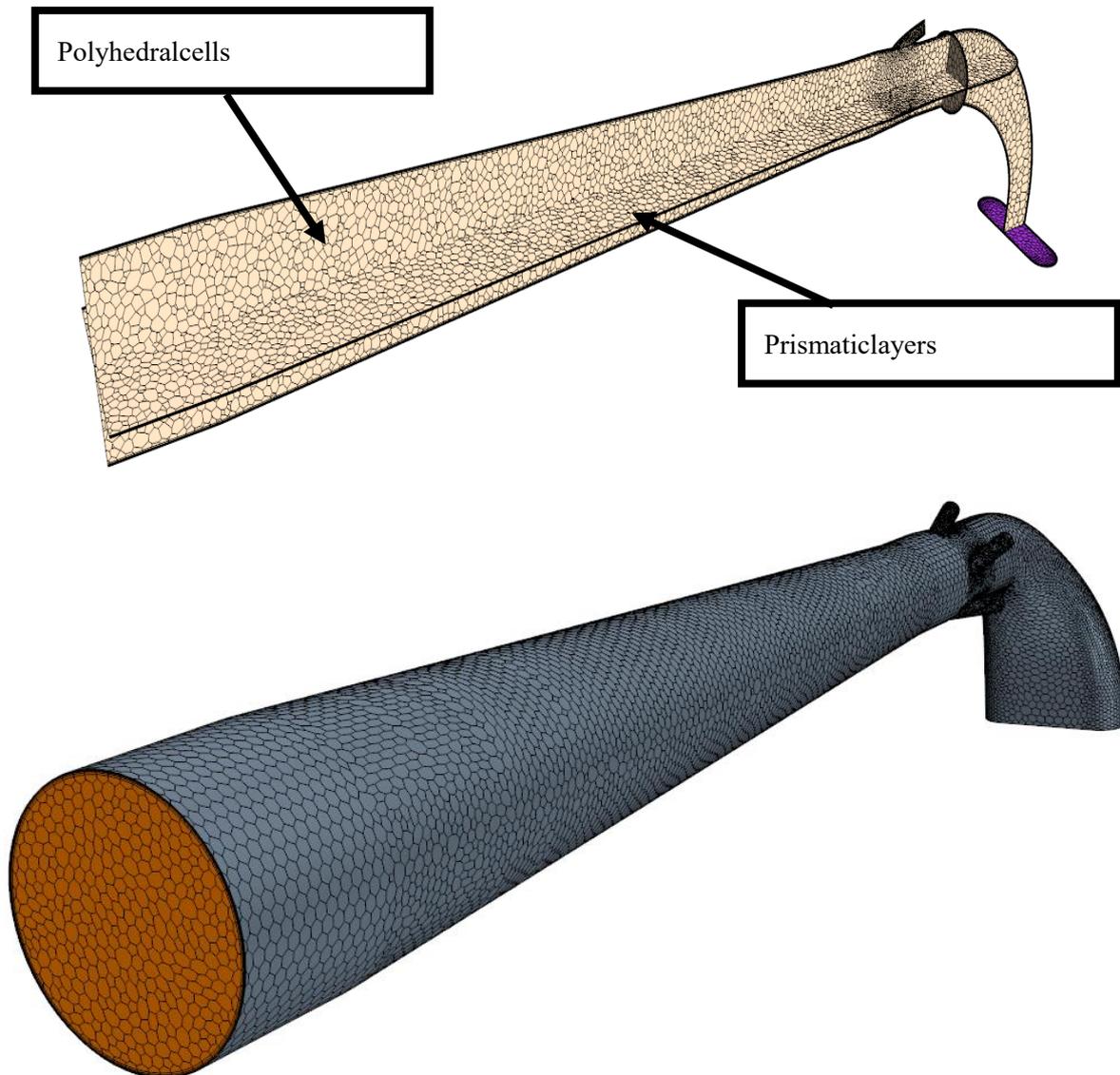


Figure2. Calculation grid

Description of the investigated model

To study the influence of the geometric parameters of the elements of the jet pump, a parameterized 3D model was made by methods of solid modeling during the development (Fig. 3).

Table 1 shows the geometric parameters that were changed during the optimization process and their ranges.

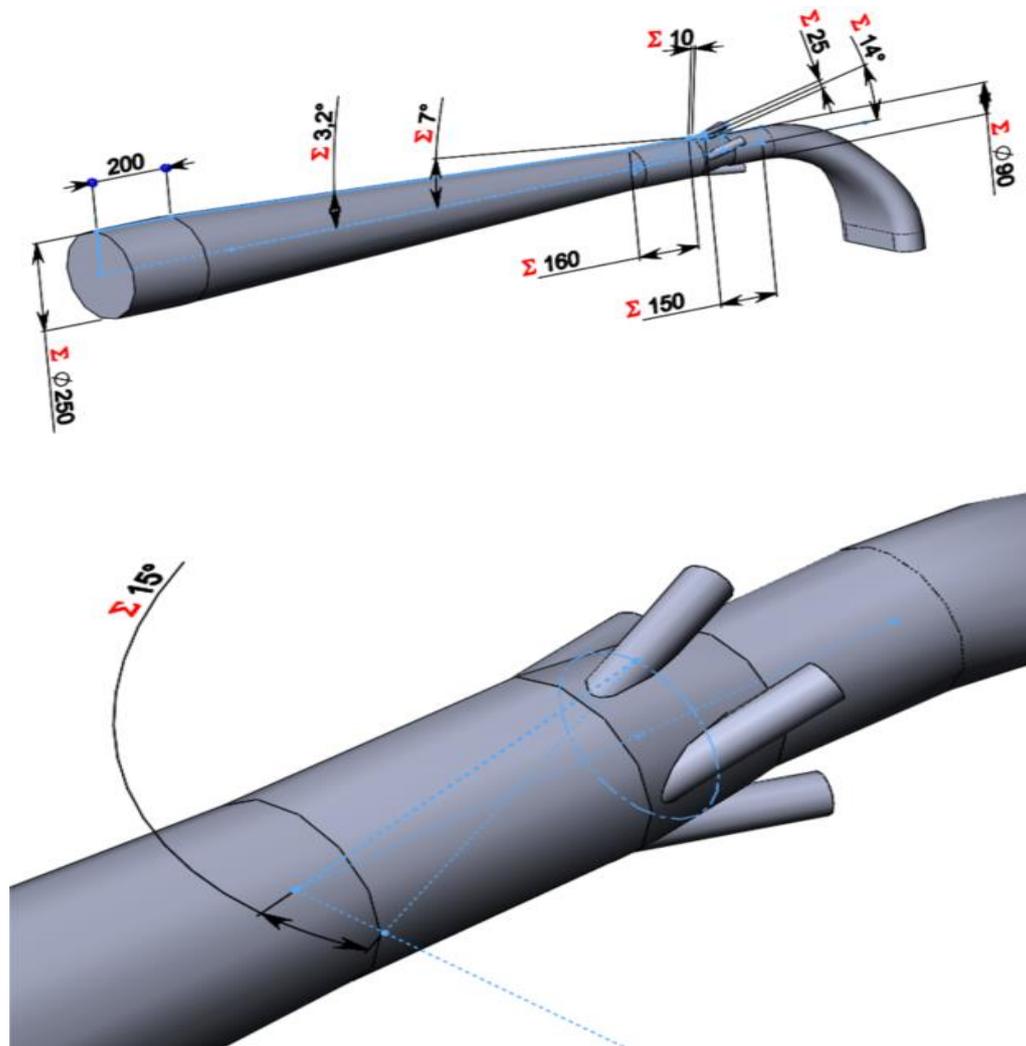


Figure3.Parameterized 3D model

Table1.Geometric parameters variation ranges

Nº	Parameter Name	Minimum	Maximum
1	Diameter of passive flow supply, D1 mm	75	100
2	Active camera input opening angle, fi3 degrees	5	45
3	Diameter of nozzles, d mm	23	27
4	The length of the stabilization section of the passive flow, l1 mm	100	200
5	Mixing chamber length, l3 mm	150	300
6	The size of the input chamber of the active stream, delta degrees	2	10
7	The angle of the nozzle to the axis, fi1 degrees	10	20
8	Circumferential angle of nozzle inclination, fi2 degrees	0	30
9	Diffuser angle, fi degrees	1	5

In order to exclude the suction section from the optimization process, i.e. vertical pipe, it is advisable to calculate it separately. Thus, its drag coefficient can be determined and used to set the boundary condition. This approach can significantly reduce the volume of the computational domain to be optimized, and the calculation time respectively.

Figure 4 shows a 3D model of the flow part (fluid) of the suction pipe. In addition to the inner flow part of the pipe, a part of the inlet volume is included as a cube for precise calculation the inlet losses.

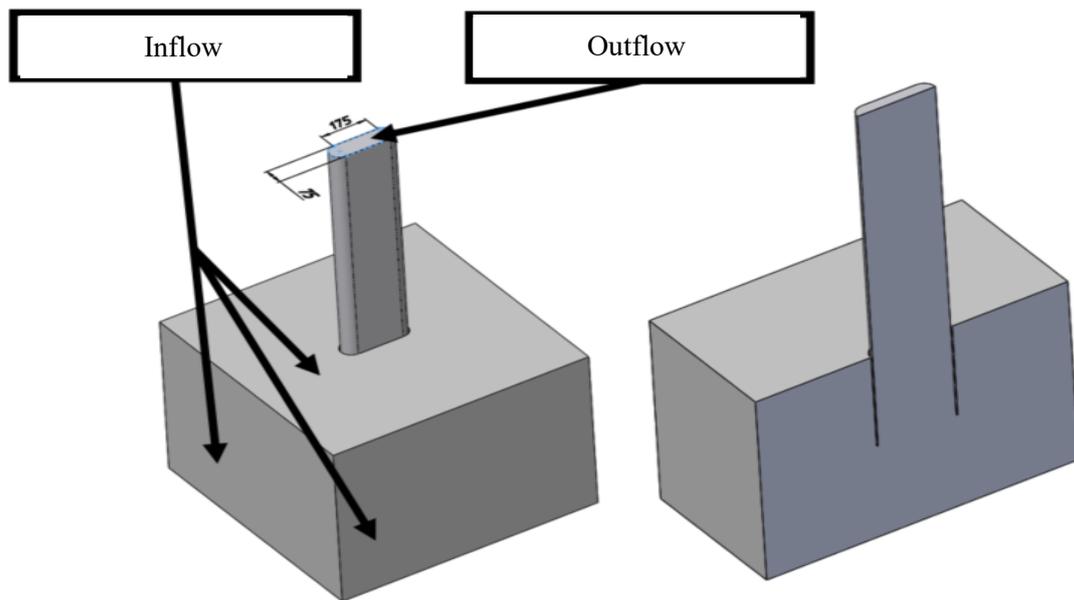


Figure 4.Flow part of the inlet area

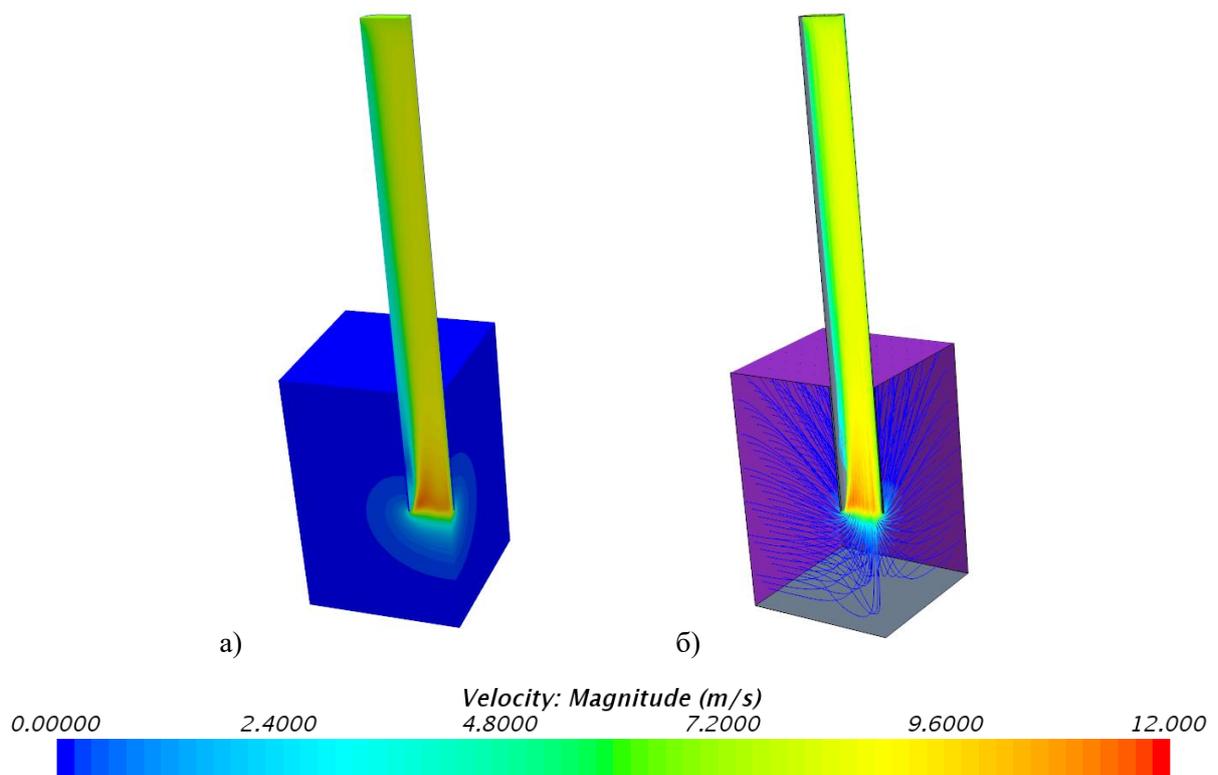


Figure 5.Distribution of velocity amplitude: a) along the planes of symmetry; b) along stream lines

The design of the calculation grid for the suction pipe is shown in Figure 4. The cells have a polyhedral shape in the flow core and prismatic near solid walls, because a finer mesh is required when computing the boundary layer.

To reduce the volume of the computational domain, the property of its geometric symmetry was used, i.e. in the process of modeling its quarter was used.

Figure 5 shows the character of the flow in the computational domain – velocity distribution along streamlines and symmetry planes.

Losses are determined according to the formula:

$$\Delta h = (P_2 - P_1) / \rho g,$$

where Δh is the value of losses, m;

P_1 and P_2 — average values of total pressure at the input and output boundaries, respectively, Pa;

ρ — fluid density, kg/m³;

g — acceleration of gravity, m/s².

Operation criteria and boundary conditions

The search for the optimal solution within the study was carried out by changing the previously given geometric parameters according to the following criteria:

1. Minimization of active flow power N_p ;
2. The aspiration of the input velocity to the target value: V .

The maximum value of the power of the active stream is determined by its flow rate and pressure:

$$N_{pMAX} = P \cdot Q$$

Figure 6 shows the flow part used in the calculations with the mentioned boundary conditions.

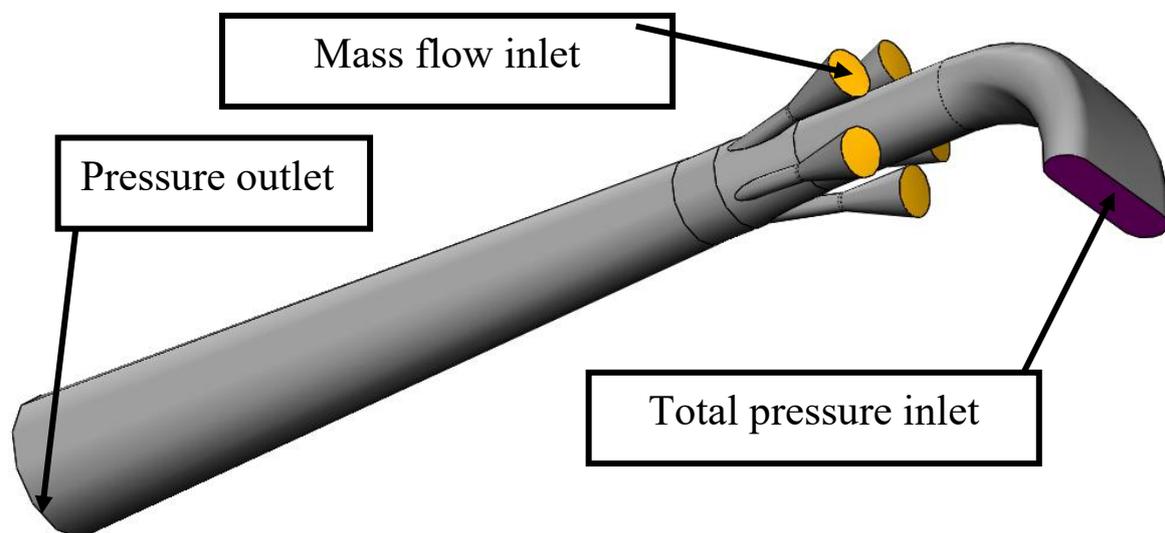


Figure 6.Boundary conditions

The total pressure of the passive flow at the inlet is determined according to the resistance characteristic of the suction pipe as follows:

$$H_{in} = \alpha \cdot V_{in}^2,$$

where:

α — a coefficient equal to the ratio of the magnitude of losses in the suction pipe to the flow rate of the liquid in it.

V_{in} — input passive flow rate.

Study results and analysis

Table 2 shows the 15 best models obtained as a result of the optimization. Power values are given in fractions of the maximum permissible, and the speed values are given in fractions of the minimum desired.

Table 2. Optimization results

№	KПД	Np	Vin	d	D1	fi_ax	fi	fi_r	l1	l3	D	delta	fi_3
1	0,111	0,907	0,849	25,7	75	12,2	4,6	13,4	111	166,5	285	6	22,7
2	0,109	0,914	0,847	25,7	75	12,2	4,6	13,4	111	250,5	285	6	22,7
3	0,210	0,919	1,055	25,2	85,8	13,9	3,2	13,4	155	150	285	6,3	8,3
4	0,210	0,921	1,055	25,2	85,8	13,9	3,2	13,4	155	160,5	285	6,3	8,3
5	0,081	0,922	0,769	26,7	85,2	13,2	2,1	1,4	191	250,5	285	5,1	25,3
6	0,219	0,927	1,071	25,2	86,8	13,3	3,2	14	155	160,5	285	6,3	7,9
7	0,076	0,932	0,752	26,8	84	12,8	1,6	2,6	112	172,5	285	5,3	28,9
8	0,087	0,935	0,790	26,6	84,6	13,1	1,9	2,2	185	250,5	285	5,3	22,9
9	0,089	0,935	0,796	26,6	86,2	13,2	1,8	2,4	187	150	285	5,7	23,5
10	0,220	0,940	1,079	25,2	87,4	13,8	3,2	14	165	160,5	285	6,3	8,5
11	0,220	0,942	1,080	25,2	87,4	13,8	3,2	14	155	160,5	285	6,3	8,5
12	0,208	0,943	1,060	25,1	85,8	13,9	3,3	13,4	157	162	285	6,5	8,3
13	0,194	0,951	1,039	25,2	85,8	13,9	3,2	13,4	155	243	285	6,3	8,3
14	0,223	0,954	1,089	25,1	87,4	13,8	3,3	14	157	162	285	6,5	8,5
15	0,232	0,954	1,103	25,2	88,8	13,8	3,2	14	155	160,5	285	6,3	8,5

Figures 7 and 8 show the dependences of the efficiency and speed in the suction pipe on the opening angle of the diffuser, the diameter of the nozzle, and the diameter of the mixing chamber.

The efficiency of the jet pump in this case is determined as follows:

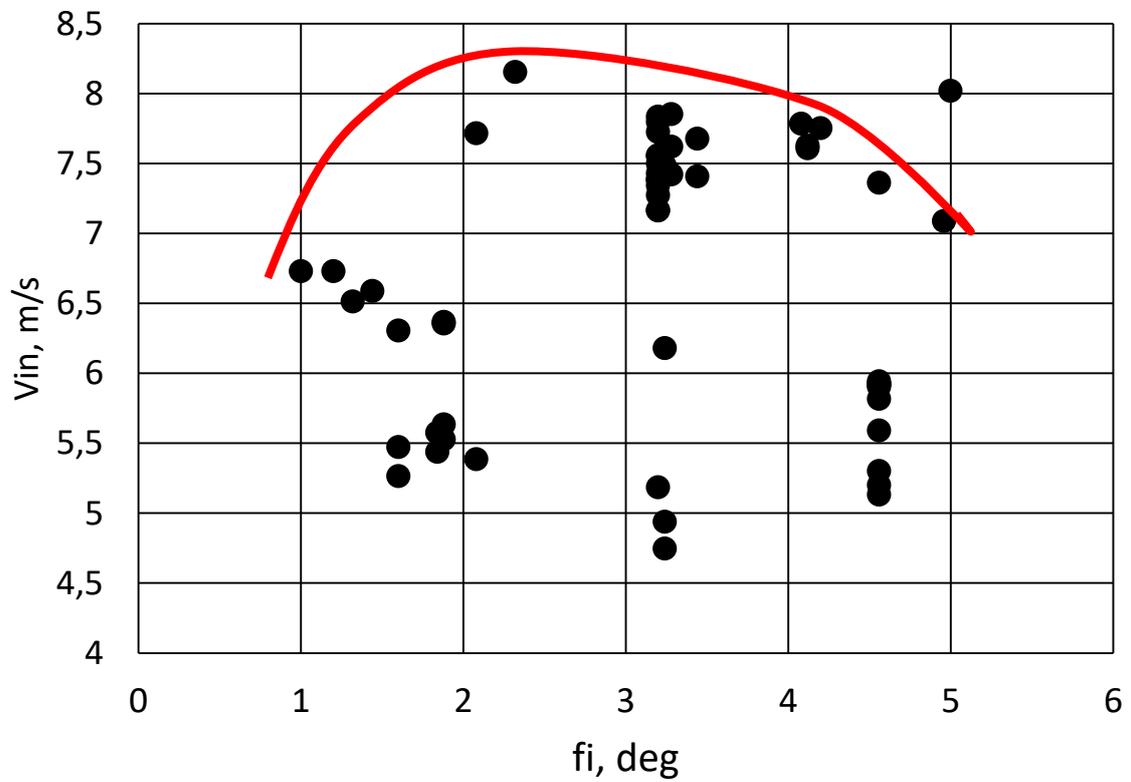
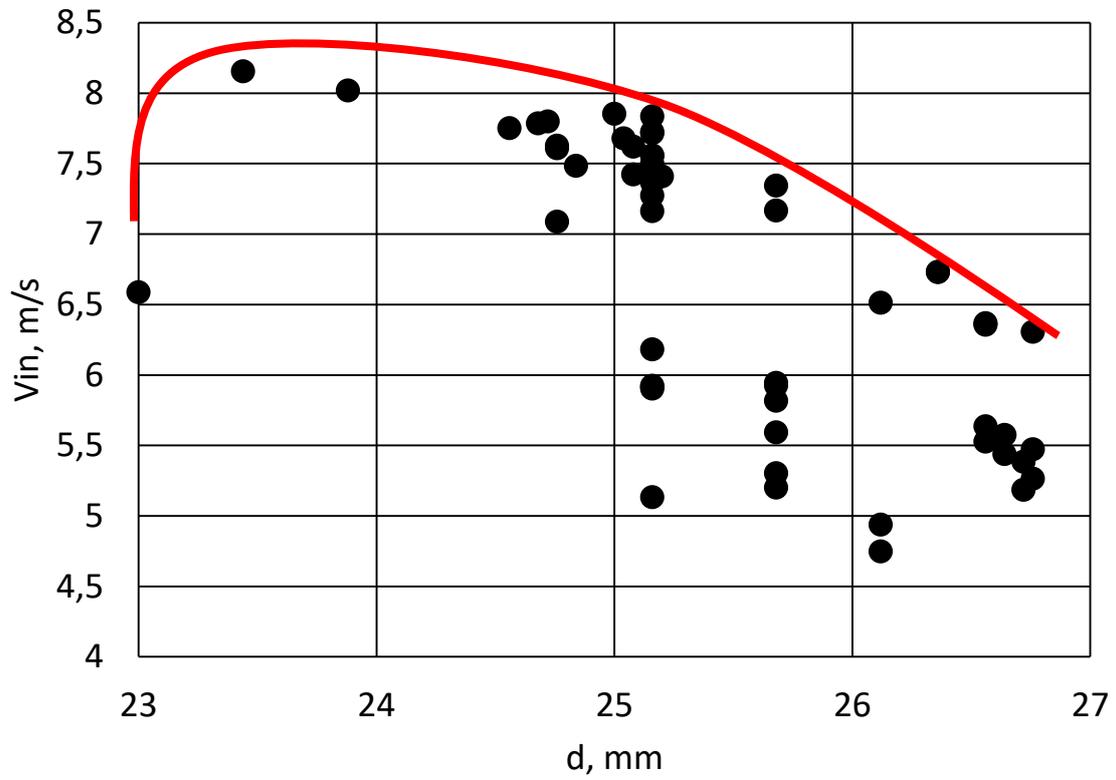
$$\eta = \frac{N_2}{N_1};$$

Where:

N_2 — passive flow power,

N_1 — active flow power.

The choice of the useful work is explained by the main task of the pump — suction of the liquid-soil mixture.



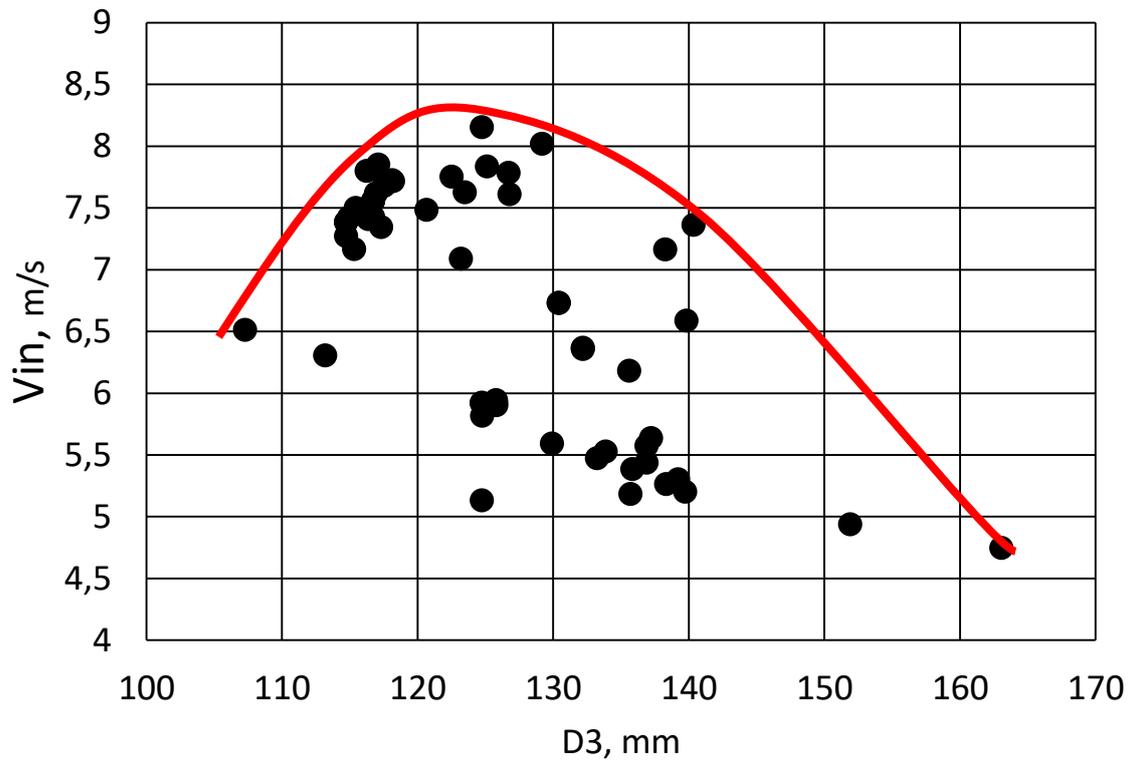
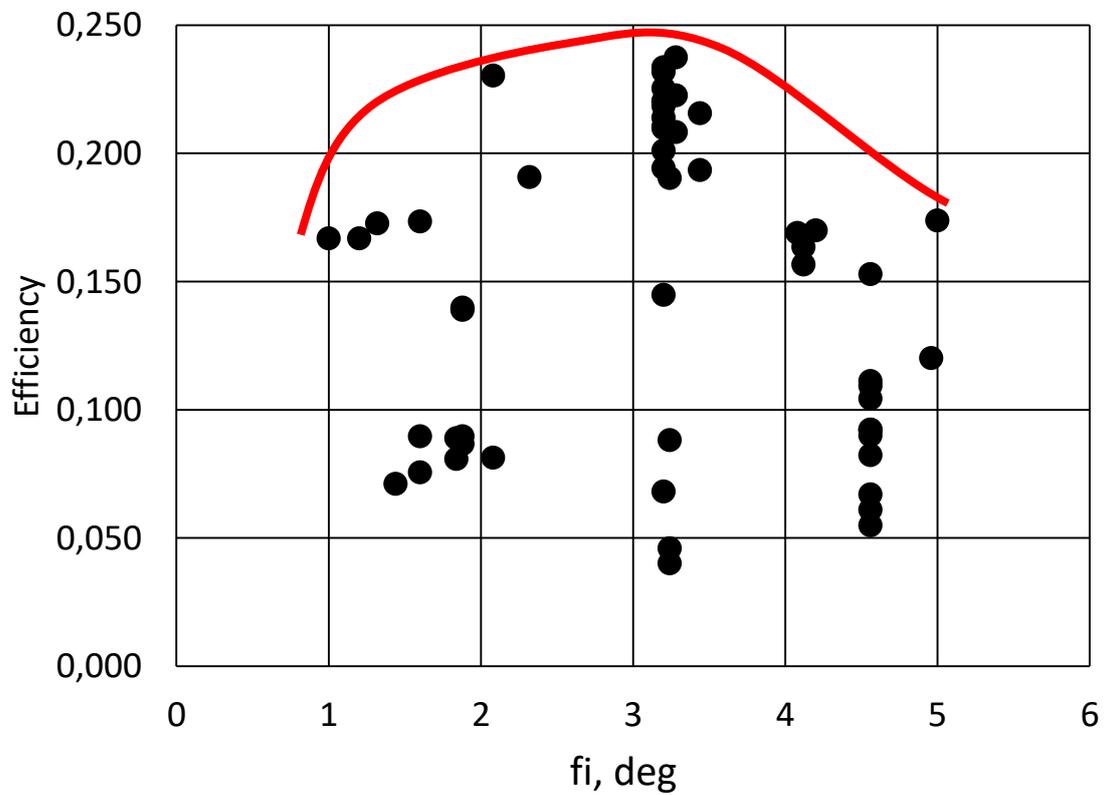


Figure 7. Dependences of speed in the inlet pipe on its geometric parameters



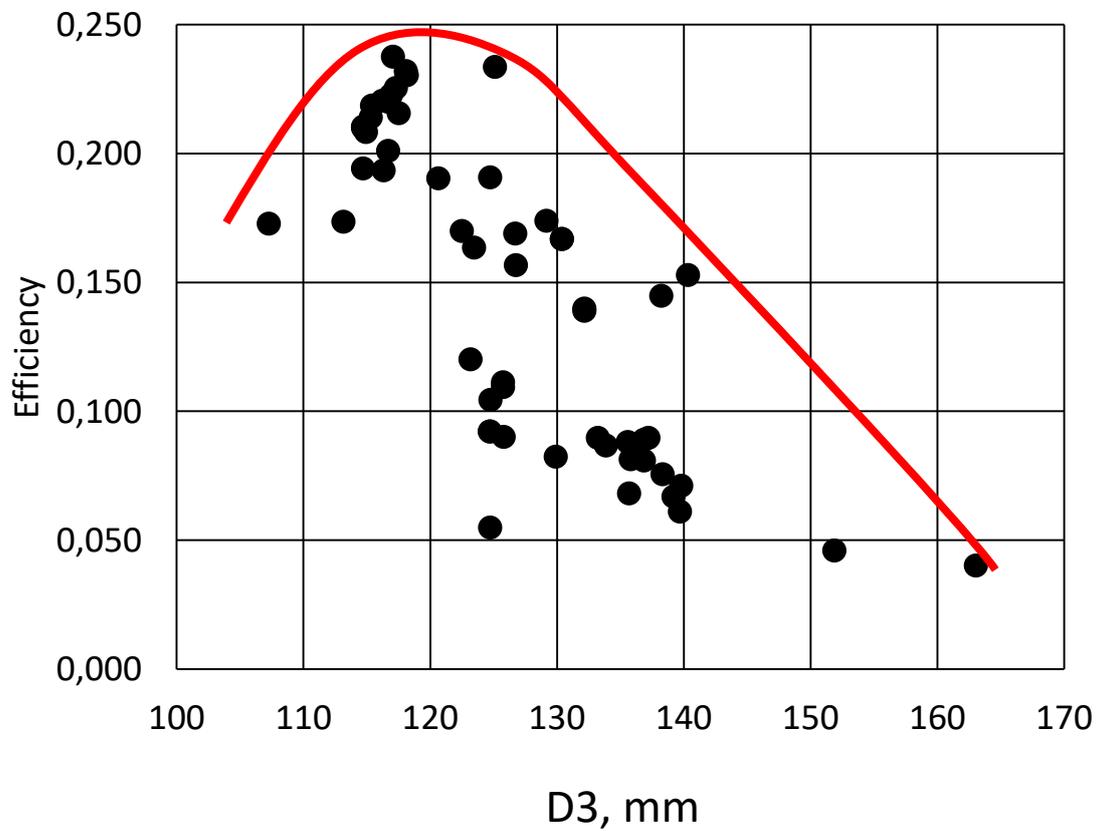
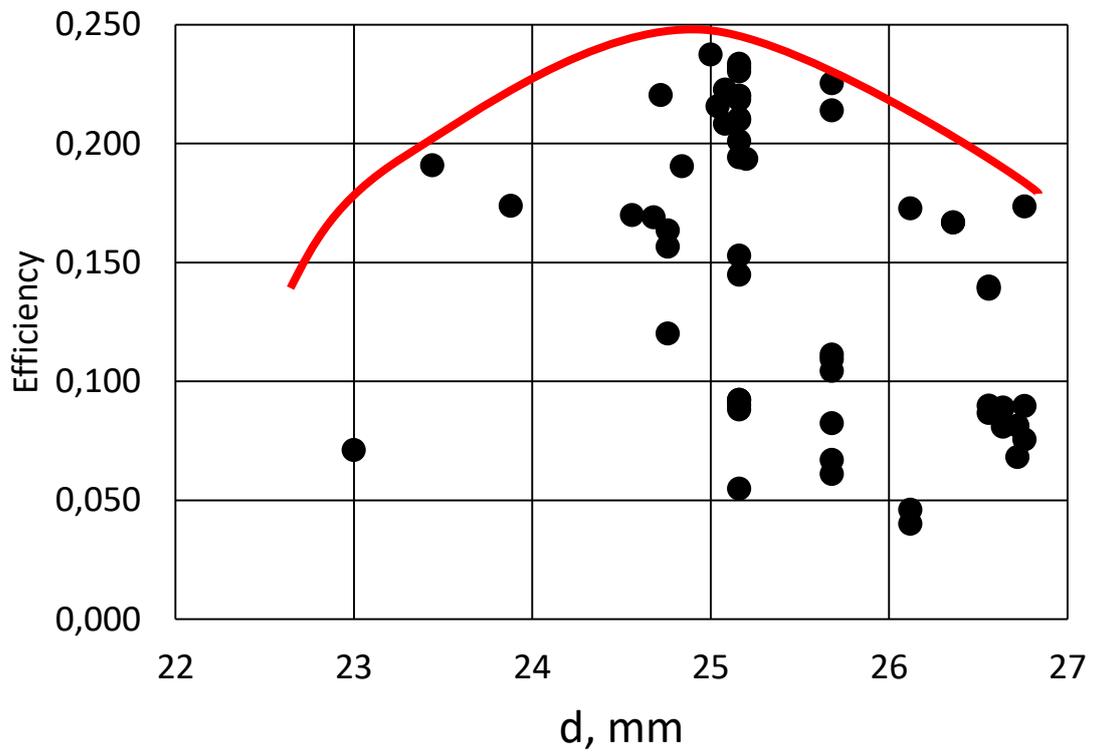


Figure 8.Efficiency dependencies on the geometric parameters

Conclusion

In the process of optimization the required speed value in the suction pipe was obtained, the power value was kept within permissible limits, and the highest value of the efficiency was achieved by changing the geometric dimensions of the elements of the flow part of the jet pump.

According to the optimization results, the dependences of efficiency, speed in the inlet pipe and power on the geometric parameters were obtained. The most demonstrative of them were given in this article.

It should be noted that the most effective diffuser opening angle turned out to be 3.2° , which is less than the recommended values for the opening angle of classical stream ($10-12^\circ$). Most likely, this is due to the peripheral disposition of the nozzles of the active stream.

To reduce the time and volume of calculations, the inlet suction pipe was calculated by hydrodynamic modeling methods, its drag coefficient was determined and used to set the total pressure at the inlet.

Thus, in the course of the study, it was managed to obtain a flow part capable of performing the tasks facing the designed jet pump, and some interesting dependences were obtained.

References

- [1] Kalachev V. V. Strujnyenasosy. Teoriya, raschetiproektirovanie. 2017.
- [2] Wang, X., Chen, Y.L., Zhao, Y., Xu, Y., Wang, B. Influence of suction chamber profile on flow field of annular jet pump. IOP Conference Series: Earth and Environmental Science. Vol 3.4, issue 3, 2019. DOI: 10.1088/1755-1315/304/3/032088.
- [3] Panevnik, A.V. Choosing diameter of the operating nozzle of a hole jet pump. Neftyanoe khozaystvo - Oil Industry, 2002.
- [4] Darbandi, M., Sabzpoushan, S., Schneider, G. Geometrical optimization of a steam jet-ejector using the computational fluid dynamics. Vol 2, 2018. DOI: 10.1115/FEDSM2018-83203.
- [5] Cheremushkin V.A., Petrov A.I., Chaburko P.S. Using Stator Blades in Accessory Tracts of Hermetic Pumps // Mashiny i Ustanovki: Proektirovanie, Razrabotka i Ekspluatsiya. 2017, no. 2, pp 1–12
- [6] Lomakin V O 2015 Investigation of two-phase flow in axial-centrifugal impeller by hydrodynamic modeling methods Proceedings of 2015 International Conference on FluidPower and Mechatronics, FPM 2015 no 7337302 pp 1204–6
- [7] Lomakin V. O. Complex optimization of the wet part of the hermetic pump by the LPTau search method // Pumps. Turbines. Systems. 2016, no. 1 (18), pp. 55–61
- [8] Lomakin V, Cheremushkin V and Chaburko P 2018 Investigation of vortex and hysteresis effects in the inlet device of a centrifugal pump 2018 Global Fluid Power Society PhD Symposium, GFPS, no 8472374 DOI: 10.1109/GFPS.2018.8472374
- [9] Tesch K, and Kaczorowska-Ditrich K 2018 Discrete-continuous optimization of an axial flow blood pump 23rd Fluid Mechanics Conference, FMC 2018 (Zawiercie, Poland) 1101 DOI: 10.1088/1742-6596/1101/1/012044
- [10] V. Cheremushkin and A. Polyakov 2019 Optimization of the output device of a disk pump for high viscous fluid. IOP Conf. Series: Materials Science and Engineering 589 (2019). doi:10.1088/1757-899X/589/1/012001