

Article

Study of an Ejector Water Intake and Treatment Plant with a Pressure-Vacuum Hydrocyclone

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Abstract: The intake of natural water or waste water from a depth exceeding the suction height of centrifugal pumps is mainly carried out due to additional water supply at the suction of the pump. However, this process becomes more complicated if it is necessary to purify water from mechanical impurities. The purpose of the presented work is to consider this issue based on the development and study of the parameters of an ejector water intake treatment plant equipped with a pressure-vacuum hydrocyclone. The main contribution of the ongoing research is the establishment of the technological parameters of the installation, and their features in the pressure-vacuum mode of operation, in contrast to the known pressure and vacuum hydrocyclones separately. In terms of methodology, the main parameters of the developed installation were established during the testing of its prototype on a specially built stand using well-known regulatory guidelines in the hydraulic research system. As a result of the study, the nature of the change in pressure inside a cylindrical–conical hydrocyclone, with established design dimensions and the patterns of formation of vacuum and pressure-vacuum modes depending on the initial parameters, was revealed. The data obtained to determine the effect of technological parameters of ejection and the characteristics of the supplied water with impurities on the operating mode of the hydrocyclone confirm the efficiency of water intake and purification. A rational mode of joint operation of the elements of a closed system is achieved at the maximum value of the installation efficiency and ensuring low specific energy consumption per 1 m³ of treated water.

Keywords: ejector plant; hydrocyclone; water lifting and purification; pressure-vacuum mode; operating parameters



Citation: Kassymbekov, Z.; Kuldeev, Y.; Kassymbekov, G. Study of an Ejector Water Intake and Treatment Plant with a Pressure-Vacuum Hydrocyclone. *Water* **2022**, *14*, 2855. <https://doi.org/10.3390/w14182855>

Academic Editor:
Anastasios Zouboulis

Received: 23 June 2022
Accepted: 7 September 2022
Published: 13 September 2022

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1. Introduction

The experience of using the principles of ejection of water from underground and surface sources by combining a pump and jet apparatus has shown the effectiveness of their application, especially when it is necessary to increase the suction height of pumps [1–4].

As experimental data show, with an increase in the ejection coefficient, the water productivity increases. However, the critical value of ejection (0.85–0.95) does not allow a further increase in water flow, and therefore, this limit must be taken as the calculated one during design and operation [2].

A positive example of ejection on the suction pipeline of vane (soil) pumps is pump–ejector installations widely used on dredgers and various water intake structures [5–9]. Their use helps to increase the suction capacity of dredgers and reduce cavitation wear [8].

The developed design of a double water jet pump [10], as the main element of a closed circuit, is successfully used for pumping both clean and contaminated fluids from hydrogeological wells.

If it is necessary to clean the lifted liquid from various mechanical impurities or to take the water-ground mixture from the water source, additional water treatment devices are

used, mainly in the form of hydrocyclones of various designs and operating modes [11–17]. This is due to the fact that hydrocyclones are characterized by their high performance and ability to efficiently clean water from mechanical impurities at a relatively small size and cost, with low resource costs for operation. The results of measuring the parameters of the classification of suspended solid particles by size in a hydrocyclone equipped with an additional water injection mechanism show that such an arrangement significantly changes the characteristics of the hydrocyclone in a positive direction [11]. This is confirmed by the results of another work on a similar topic [12], which presents the hydrodynamic characteristics of a hydrocyclone equipped with a mechanism for additional water injection into the apparatus. The dependencies of the change in water flow through the drain pipes and the lower sand pipes are established.

In the conducted experimental studies, attention is mainly paid to the issue of achieving a high efficiency of separation of mechanical impurities from the liquid composition by improving the technology used [13–15]. The article [18] states that the excessive width of the flat bottom structure increases the number of large particles out of place in the overflow, which causes increased turbulence intensity.

To study the technological process and predict the separation of particles by size, as well as on the basis of these data to establish rational parameters of hydrocyclone devices, many works on mathematical, numerical, and computer modeling have been published [19–28]. In the article [20] in particular, a search was made for a suitable turbulence model for hydrodynamic forecasts in industrial hydrocyclones. Here, the effect of turbulence on particles in hydrocyclones is analyzed by the dispersion index formula. It has been established that a hydrocyclone with a spiral inlet has a lower kinetic energy of turbulence and a more stable flow field compared to a traditional hydrocyclone with a tangential inlet [23], and the tangential injection method has a stronger effect on the separation curve compared to the radial method [24].

The results of the influence of various designs of the hydrocyclone inlet, drain pipe, and lower sand hole on the expected technological parameters are given and analyzed in scientific papers [29–35]. As noted in [31], the design of a hydrocyclone with a drain pipe supplemented with a bulk filter makes it possible to increase the efficiency of trapping mechanical impurities on 12% in comparison with a typical apparatus, and with an extended top drain, it has a closer profile to a quasi-rigid rotation. The bottom stream is usually adjusted to overcome variable feed conditions, thereby providing the desired performance [36].

Issues of improving hydrocyclone performance by controlling the internal structure of turbulence and using a high-pressure hydrocyclone to classify particulate matter in the submicron range are considered to a fairly high degree in the articles [37,38]. As indicated in [39–41], the separation capacity of hydrocyclones is also significantly affected by the correct choice of the lower flow line and the presence of an air core.

An important element in the research of hydrocyclone installations is the optimization of the structural and technological parameters of the hydrocyclone with the classification of small and large particles [42–44]. At the same time, issues of reducing the abrasive wear of the hydrocyclone and pumping equipment, as well as energy costs, are relevant. The developments carried out in the Kazakh Research Institute of Water Management in this direction have shown that this issue can be effectively solved by creating a vacuum or pressure-vacuum mode of operation in hydrocyclones. To do this, the hydrocyclone is installed on the suction line of a centrifugal pump, and water is supplied to it using an ejector [2,45].

This arrangement of the hydrocyclone with the base pump and the action of the additional ejector on the cleaning process, to a certain extent, affects the nature of the change in the parameters of the working process. The results of the study of these features determine the scientific novelty of the studied pressure-vacuum regime in a hydrocyclone in comparison with the data of the analyzed literature.

2. Materials and Methods

A structural diagram of a catchment well equipped with an ejector and a hydrocyclone is shown in Figure 1a [2]. It consists of a catchment well 1, of a centrifugal pump 2, a hydrocyclone 3, an ejector 4, and a filter 5.

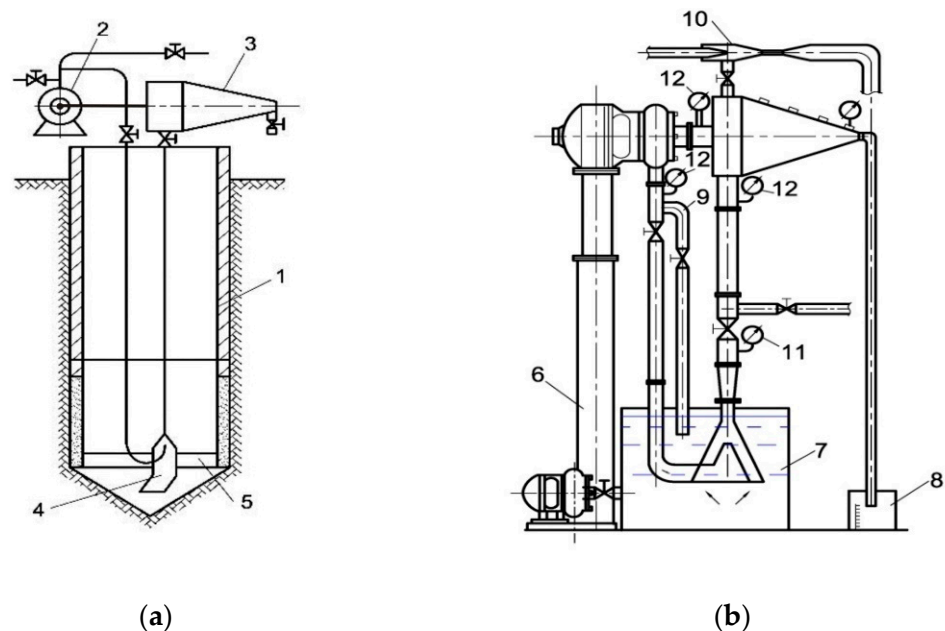


Figure 1. Scheme of the design (a) and the stand for the study of the ejector–hydrocyclone installation (b). 1—water collector; 2—centrifugal pump; 3—hydrocyclone; 4—ejector; 5—filter; 6—telescopic stand; 7—water intake tank; 8—measuring tank; 9—additional branch; 10—mini ejector; 11—manometers; 12—vacuum gauges.

When the pump 1, located on the surface, is turned on, water is supplied under pressure to the working nozzle of the ejector 4. Due to the ejection pressure, the suction water enters the hydrocyclone 3 installed on the pump suction. The tangential entry of water into the hydrocyclone creates a swirling flow in which solid particles are separated from the composition of the water. In the adopted scheme, the hydrocyclone can operate in a pressure-vacuum mode, because a vacuum is formed in the zone of the hydrocyclone drain pipe due to the suction of the pump, and the residual pressure from the ejector is maintained in the cone part. The purified water is sucked in by the pump, and a certain part of it is transferred back under pressure to the ejector head as a working fluid.

Figure 1 shows a general view of the experimental stand for studying the main parameters of the developed installation.

Here, in addition to the above main elements of the installation, there is also a telescopic rack 6, with the help of which, the suction height of the pump is adjusted.

The hydrocyclone was made of Plexiglas, which provided visual observation of the process taking place in it. The ejector and the front part of the receiving tank 7 were also made transparent. Tank 8 with dimensions of $0.5 \times 0.5 \times 0.4 \text{ m}^3$ was designed to determine the flow of water through the sand hole of the hydrocyclone.

The flow rate of water flowing out through the outlet of the hydrocyclone Q_2 was set using an additional outlet 9. The installation was charged in two ways: by supplying water from the water supply to the installation or using an ejector 10 with an individual pump under flooding.

The pressure values at characteristic points (at the inlet of the hydrocyclone chamber P_1 , at the outlet of the hydrocyclone P_2 , at the discharge line of the pump P_p , and downstream of the ejector diffuser P_e) were set using pressure gauge 11 and vacuum gauge 12.

The static pressure field in the cross sections of the hydrocyclone chamber was established using a special probe with a cylindrical tip and a through-hole at the end.

The technological scheme of the stand in a closed cycle ensures the continuity of the testing of the installation for the intake and purification of the raised water.

In the first version of the study, the processes of pressure changes inside a cylindrical-conical hydrocyclone with accepted design dimensions (Table 1) and the patterns of formation of vacuum and pressure-vacuum modes depending on the initial parameters were studied. In this case, the pressure gradients were recorded in the characteristic sections of the hydrocyclone, covering all the working areas of the cyclone flow.

Table 1. Structural dimensions of the hydrocyclone.

Dc	Diameters, mm			T ₁ , mm	T ₂ , mm	T, mm	α_k
	d ₁	d ₂	d ₃				
240	50	50	20	120	345	465	15–30°

The dimensions of the tested ejector were taken in the following values: the diameters of the working nozzle $d_p = 10$ mm, the mixing chamber $d_{mc} = 24$ mm, and the diffuser $d_d = 50$ mm.

The total flow rate of the ejector Q_e was taken as equal to at least the flow rate of the base pump (3 KM-6) Q_p , which is equal to the water flow rate through the hydrocyclone outlet Q2 and is determined as the sum of the flow rates $Q_e = Q_0 + Q_1$, where Q_0 is the suction flow rate of water with impurities, and Q_1 is water flow through the working nozzle of the ejector from the pump.

Here, D_c is the diameter of the cylindrical part of the hydrocyclone; d_1 -, d_2 -, and d_3 —diameters of the inlet, drain, and lower branch pipes; T , T_1 , and T_2 —heights of the main elements of the hydrocyclone (general, cylindrical, and conical parts); α_k —taper angle.

The value of the relative pressure was determined from the ratio of the pressure developed by the ejector h_e (according to the readings of the pressure gauge behind the diffuser) and the pump pressure H_p —from the pressure gauge installed in front of the working nozzle. The emission factor (α_e) was given by the relation:

$$\alpha_e = \frac{Q_2}{Q_1} - 1 \quad (1)$$

Then, studies were carried out to determine the effect of technological parameters of ejection and the characteristics of the supplied water with impurities on the operating mode of the hydrocyclone.

The next series of studies was devoted to evaluating the effectiveness of the ejector–hydrocyclone technology and establishing an economical mode of joint operation of elements of a closed network for lifting and water purification. This mode was set according to the maximum value of the efficiency of the installation η_p and low specific energy consumption per 1 m³ of condensed mass N_u .

A study on the study of the redistribution of fluid flow rates between the discharge openings of the hydrocyclone was carried out with a change in the geometric parameters of the hydrocyclone chamber within $d_3/d_2 = 0.3$ –0.5.

The efficiency of separation of mechanical impurities in the hydrocyclone and the system as a whole was evaluated by the following indicators:

The degree of water purification in the hydrocyclone:

$$E_h = 100 - \frac{Q_2^1}{Q_1} \quad (2)$$

where Q_2^1 —sand flow through the drain pipe, m^3/s ; Q_1 —water flow through the inlet pipe, m^3/s ;

Loss of water through the sand hole of a hydrocyclone, %

$$\Delta_3 = \frac{(1 - K_3)Q_3}{Q_3} \quad (3)$$

where K_3 —volumetric consistency of the condensed mass through the sand hole; Q_3 —water flow through the sand hole, m^3/s ;

Specific load on the sand hole, q_3

$$q_3 = \frac{\rho_3 T_h}{f_3} \quad (4)$$

where ρ_3 —pulp density, g/m^3 ; T_h —soil productivity, m^3/s ; f_3 —working area of the thickener sand hole, m^2 .

The specific costs of the residual energy of the hydraulic elevator, given per 1 m^3 of the condensed mass N_u , are equal to:

$$N_u = \frac{N_r}{T_h} \quad (5)$$

where N_r —the residual energy of the ejector spent on the separation and thickening of the pulp in the hydrocyclone, kW:

$$N_r = \frac{\rho_1 Q_1 H_e}{102} \quad (6)$$

$H_1 = H_e$ —head at the hydrocyclone inlet, equal to the head of the ejector, m.

3. Results and Discussion

3.1. Redistribution of Pressure in the Considered Sections of the Hydrocyclone

As a comparative analysis of the operation of hydrocyclone water treatment plants shows, the working processes in hydrocyclones can be carried out both in the pressure field and in the vacuum field [11–20,45]. At the same time, the nature of the movement of a liquid with mechanical particles in a hydrocyclone and the parameters of hydrodynamic processes differ little from each other. In the case we are considering, when the hydrocyclone is located on the suction line of the pump and water is supplied to it using a water-lifting ejector, all possible modes of water purification can be created in one apparatus. When the condition $P_2 > P_e$ takes place, then the separation of the two-phase liquid in it occurs at the greatest rarefaction of the field. An increase in pressure at the inlet to the hydrocyclone P_1 due to the back pressure of the ejector leads to a decrease in the rarefaction and, at a certain value, its device switches to the pressure mode of operation. At the moment of transition to the pressure-vacuum mode of operation in the near-wall (peripheral) zone of the cylindrical part of the hydrocyclone, an overpressure field arises, and a vacuum is maintained at the pump intake. With an increase in the backwater at the inlet P_e , the field propagates towards the cone and, at a certain value, covers the area of the sand hole, resulting in the free removal of solid particles into the atmosphere. The regime of fluid movement in a hydrocyclone under pressure-vacuum conditions, as shown from the above, takes place when the double inequality is observed: $0 < P_1 < P_2$. This happens when the relation P_1/P_2 belongs to the interval $[0,1]$. In this case, $P_1 > P_{\text{atm}}$, $P_2 < P_{\text{atm}}$, where P_{atm} is the atmospheric pressure, P_a . The given conditions for the transition from one regime to another are clearly seen from the profiles obtained during the experiments (Figure 2).

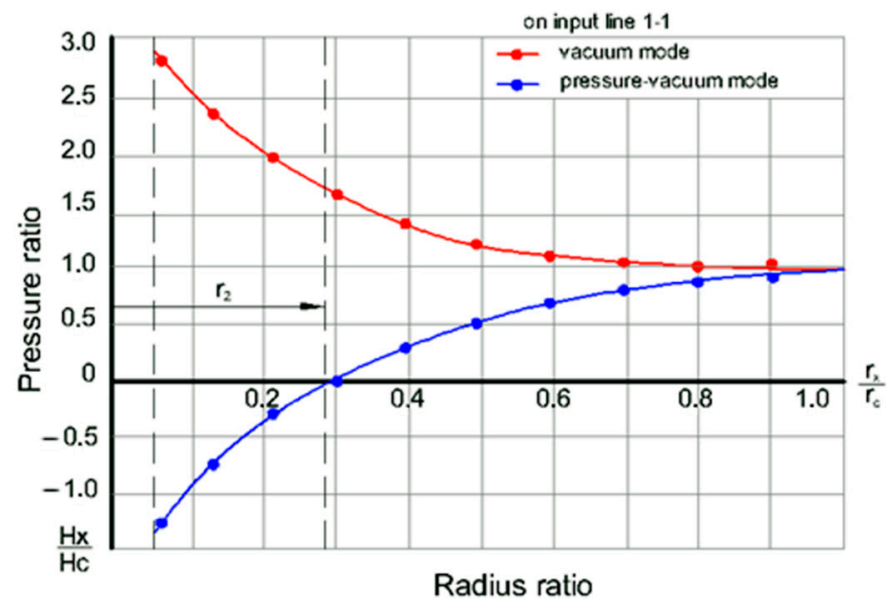


Figure 2. Dependency graphs $H_x/H_1 = f(r_x/r_h)$.

As can be seen from the figure, at a pressure at the inlet to the hydrocyclone within $P_1 = 0\text{--}5$ kPa, a vacuum field is completely established inside the hydrocyclone apparatus, which has a minimum value in the near-wall zone. A more significant deepening of the vacuum in the area of the drain pipe provides an intensive flow of liquid into the suction pipe of the pump. The pressure profiles of the flow in the pressure-vacuum mode of operation of the hydrocyclone present a somewhat different picture. In this case, when $P_1 = 10\text{--}15$ kPa, the vacuum field is observed only in the central part of the hydrocyclone, and the peripheral zone in height is in overpressure. In this case, the generalized curve for all can be described by the following empirical relationship (Figure 2). With a decrease in the flow rotation radius, the value of excess pressure decreases, and at the point of intersection with the line of the radial section it is equal to zero, i.e., the absolute value of liquid pressures is equal to the atmospheric pressure $P_a = P_{atm}$. In both cases, in the center of the hydrocyclone flow along the apparatus, a space is formed that is not filled with liquid (an air column). In this case, the generalized curve for all sections can be described by the following empirical relationship (Figure 2):

H_x , where H_x is the head on the considered hydrocyclone section radii, m; r_h , r_x are the radii of the hydrocyclone and in the studied sections, m.

As can be seen from Figure 3, the set of flow turbulence settings provides correct modeling of the required process, which confirms the obtained pressure distribution isolines at the beginning of the transition to the pressure-vacuum mode in the hydrocyclone.

$$H_x = H_1 \left(0.879 \ln \frac{r_x}{r_h} + 0.985 \right) \quad (7)$$

$$\frac{H_x}{H_1} = 0.879 \ln \frac{r_x}{r_h} + 0.985 \quad (8)$$

In this case, the calculation was carried out using the SolidWorks program (Flow Simulation module) for the numerical simulation of gas and liquid flows. Turbulence was calculated from the modulus of turbulence ($k\text{--}\epsilon$). The grid adaptation tab was selected at level 2, and the maximum number of cells allowed was 8,200,000.

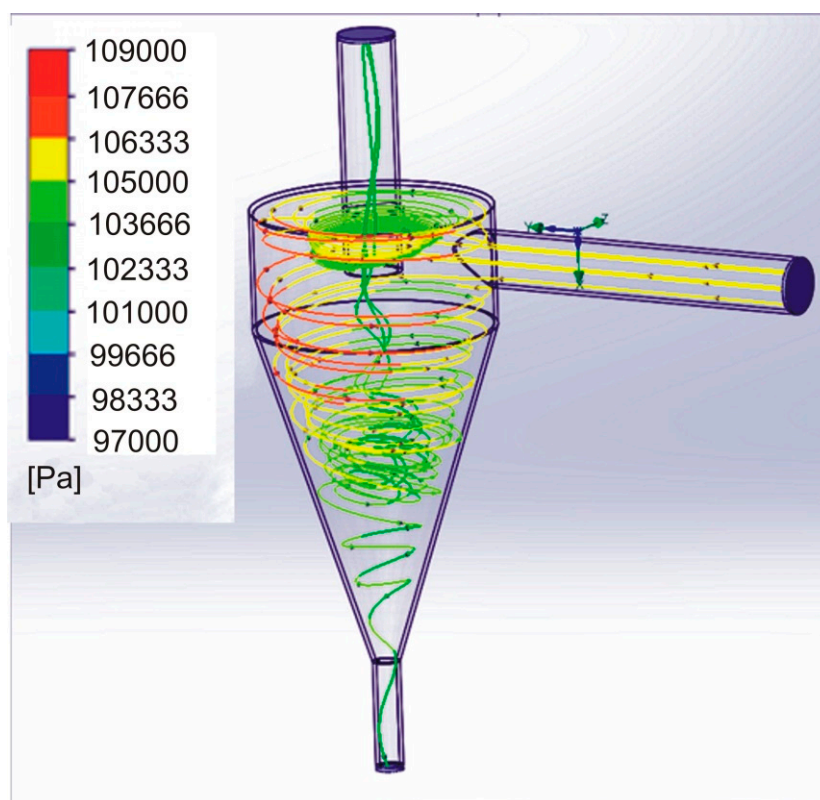


Figure 3. Isolines of pressure distribution in the hydrocyclone in the pressure-vacuum mode.

It also follows from these studies that the beginning of the free removal of liquid from the sand hole corresponds to the ratio $\frac{P_1}{P_2} > 1.2$, and at pressures $P_1 = 5\text{--}7.5$ kPa, the vacuum field is preserved at the sand hole. At the end point of the working zone, the residual pressure P_3 was relatively high, which allowed for additional thickening of the pulp and its removal from the hydrocyclone to the outside. It has been established that the flow rate through the sand hole increases with an increase in the relative pressure of the ejector.

3.2. Redistribution of Water Flow in the Hydrocyclone between Discharge Openings

The peculiarities of water flow redistribution become noticeable when the ejector head H_e exceeds the cantilever pump inlet head H_p by one order of magnitude or, at least, when they are equal to each other, which ensures hydrocyclone operation in the under-pressure conditions. The pressure loss in the hydrocyclone is $\Delta h = 15\text{--}30$ kPa.

(Figure 4). It is characteristic that in the thickening mode, when the pressure at the hydrocyclone inlet exceeds $P_1 = P_e = 55\text{--}60$ kPa, the relative thickening index decreases to $K_o = 2.8\text{--}3.0$ and thus the water losses increase by 10–15%. This shows the inefficiency of the unit in the full pressure mode.

Water losses are reduced to the lowest value, $\Delta w = 2.5\text{--}3.0\%$, when creating the pressure-vacuum mode ($P_1 = 40\text{--}50$ kPa), although the specific load on the sand hole does not exceed the allowable value ($q_3 = 1.9$ t/h cm²), adopted for the size of the sand hole ($d_3 = 20\text{--}25$ mm) (Figure 5).

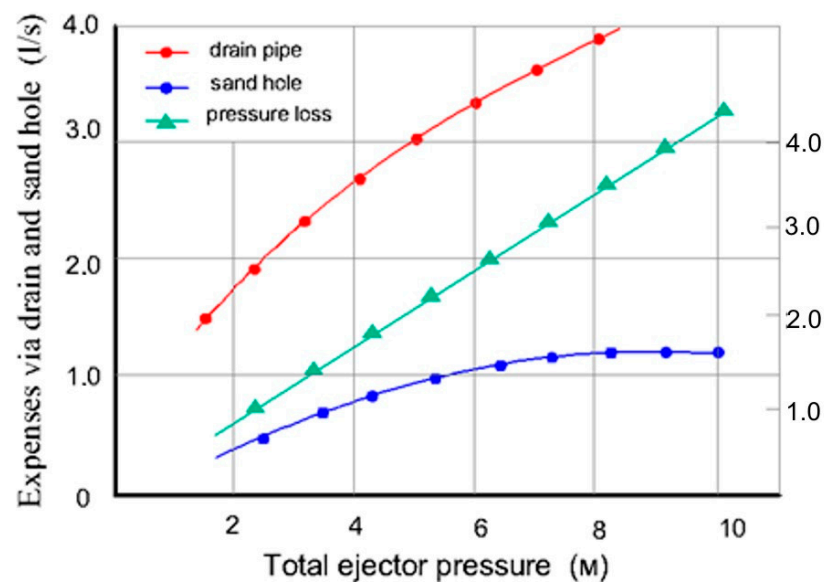


Figure 4. Loss redistribution between the discharge holes of the hydrocyclone.

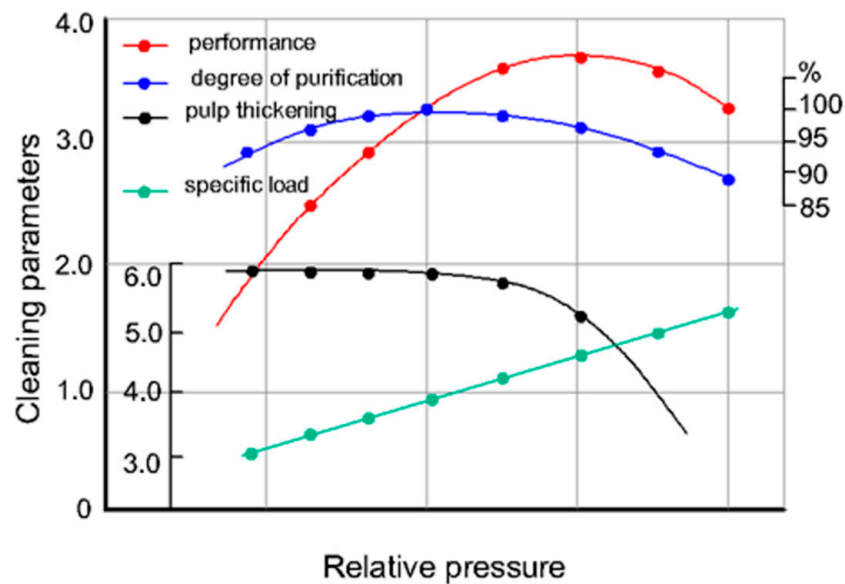


Figure 5. Technological parameters of the "ejector-hydrocyclone" system.

The hydrocyclone plant operation under vacuum conditions was not considered due to the lack of necessity for the investigated scheme of the water-pool lift and catchment well design simplification.

The high relative thickening ($K_o = 5.10\text{--}5.84$) of slurry with the lowest water losses through the sand hole was supposed to be achieved during the hydrocyclone operation with the formation of sand accumulation at the sand hole outlet.

Experimental data obtained in the indicated mode on the solid phase distribution between the discharge openings of the apparatus are shown in Table 2.

Table 2. Solid phase distribution of the pulp between the hydrocyclone discharge holes.

Inlet Pressure P_1 , kPa	Hydrocyclone Elements	Fluid Flow, l/s	Pulp Consistency	Sand Composition, % (Less than 0.05 mm)
65	Inlet nozzle	6.103	0.164	$\frac{100}{0.45}$
	Drain nozzle (overflow)	4.877	0.008	$\frac{5.1}{100}$
	Sand hole (underflow)	1.226	0.501	$\frac{94.9}{0.45}$
100	Inlet nozzle	5.818	0.157	$\frac{100}{0.35}$
	Drain nozzle (overflow)	4.484	0.0065	$\frac{6.3}{100}$
	Sand hole (underflow)	1.334	0.745	$\frac{93.7}{0.35}$

It follows from the above material that the sand accumulation to a height of up to $1/3$ of the hydrocyclone length does not reduce the base pump flow rate ($Q_p = 4.48\text{--}4.87$ L/s) and the water purification degree with mechanical impurities ($E_e = 93\text{--}96\%$). The water consistency passing through the drain pipe does not exceed $K_2 = 0.008$, and no particles with diameters larger than $0.04\text{--}0.05$ mm pass through, which helps to protect the pump impeller from abrasive wear.

This means that purified water can be reused for the next cycle of ejector water supply without purification and the use of additional settling tanks, unlike most of the existing ejector installations [1,5,46]. Due to this, savings in construction costs and rational lifting of water with solid particles are achieved.

It turned out that it was necessary to ensure the optimal value of the specific load on the sand hole ($q_3 = 1.5\text{--}1.6$ t/h per 1 cm^2) by adjusting the outlet cross section using a throttling device, mainly automatic, in order to maintain the indicated rational mode. Reduction in the unit productivity from the ground up to $Q_3 = 0$ occurs at hydrocyclone overloading by the thickened mass, as the drain hole fully overlapping does not allow the realization of free removal to the dump. There is a violation in the redistribution of the solid phase and a decrease in water purification systems by $30\text{--}40\%$. The redistributive nature is also affected by a change in the ratio of the sand and drain holes' sizes. Reducing this ratio increases the proportion of granular grains carried away toward the base pump suction.

Tests have shown that the density of treated (rendered) slurry was $p_3 = 2.13\text{--}2.21$ t/m³, and water losses were equal to $\Delta w = 3.84\%$ at relative thickening of slurry in the range.

$$Ko = 5.10\text{--}5.81$$

3.3. Hydrocyclone–Ejector Technology Efficiency Parameters Establishment and Economical Mode of Joint Operation

The obtained test results are presented in Figures 6 and 7, in the form of graphical dependencies $\eta_p, N_u, \alpha_e = f(h_e)$ и $\eta_u, \eta_e, N_u = f(T_h)$.

It is established that at joint operation with a centrifugal pump, the mode coefficient of efficiency, taking into account the manufacturability of the adopted closed circuit, varies within $\eta_u = 0.350\text{--}0.371$ and the dependence-change general pattern, $\alpha_e = f(h_e)$, is preserved. The values of ejection coefficients can be increased by up to $\alpha_e = 0.815\text{--}0.875$ by increasing the plant suction capacity.

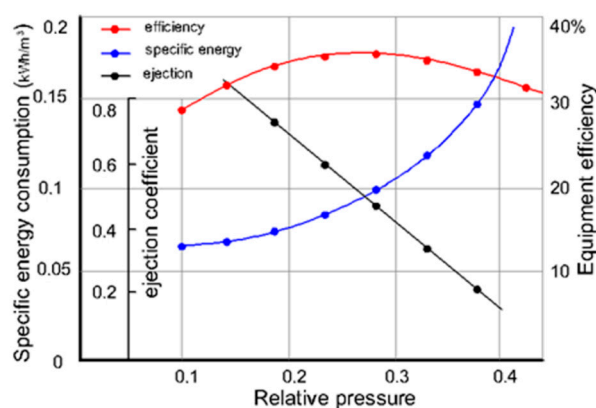


Figure 6. Dependency graphs α_e , η_u $N_u = f(h_e)$.

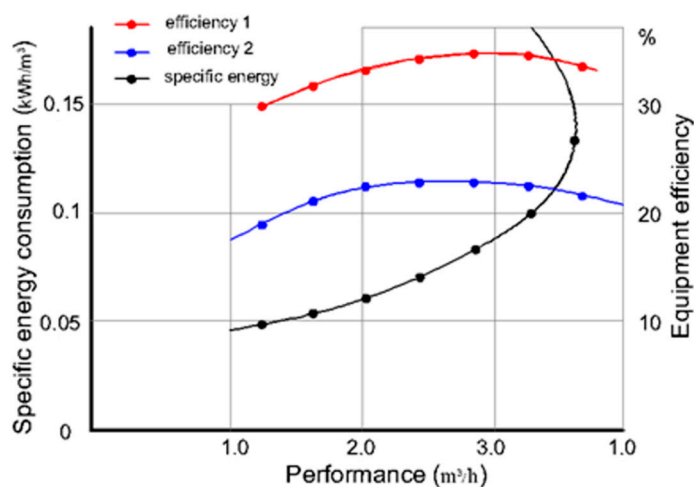


Figure 7. Regime and energy performance of the hydrocyclone plant.

A sharp jump in the value of energy consumption per 1 m³ of thickened mass is observed when the relative head increases to $h_e = 0.4$ or more, if the specific energy consumption in the working zone ($h_e = 0.250\text{--}0.310$) varies within acceptable limits. This is due to compaction of the processed sand mass in the hydrocyclone conical part and overloading of the hydrocyclone unit due to operating mode violations.

The ejector's relative pressure must therefore be taken as equal to its critical value during the operation of hydrocyclone water-lifting installations with the hydrocyclone method of cleaning and thickening. This circumstance is also confirmed in the analysis of specific energy costs depending on the productivity of the hydrocyclone on the ground T_h . The plant-given energy efficiency does not exceed the base value ($\eta_e = 0.233\text{--}0.245$), which was obtained when using an ejector to lift water from a well.

It turns out that a change in the ejector's backwater leads to a decrease in its suction capacity, and an increase in the diameter of the discharge hole increases the flow rate of the ejected stream, and consequently, the hydrocyclone productivity. It is also a characteristic that the function reaches a minimum in all discharge hole ratios at the beginning of the transition of the hydrocyclone chamber from vacuum to pressure mode.

4. Conclusions

The features of the change in the characteristics of the ejector water intake and treatment plant, revealed in the course of the study, depending on the ratio of the vacuum at the inlet to the centrifugal pump and the pressure of the ejector under the conditions under consideration, make it possible to control the operation of the installation when cleaning the raised water. At the same time, the advantages of both pressure (free mass of thickened mass) and vacuum (protection of the pump from abrasion) hydrocyclones are combined.

The established ratios of the vacuum suction head of the pump and the head at the inlet, corresponding to the boundary conditions for the formation of vacuums, pressure-vacuums, and pressure modes of fluid movement in one hydrocyclone, allow one to use the same hydrocyclone apparatus in various technological schemes of water treatment as needed.

At $P_1 = 10\text{--}15$ kPa, the vacuum field is observed only in the central part of the hydrocyclone, and the peripheral zone in height is in overpressure.

The rational technological parameters of the improved design are characterized by the water capacity of the ejector in the range $Q_e = 4.2\text{--}4.7$ L/s and the degree of purification up to 96% in the hydrocyclone.

The optimal value of the specific load on the sandbox ($q_3 = 1.5\text{--}1.6$ t/h per 1 cm^2) must be ensured to maintain the required mode by adjusting the cross section of the outlet with an automatic control valve. When overloading the conical part of the hydrocyclone with sand, the redistribution of the solid phase is violated, and the water purification is reduced by 30–40%. The change in the ratio of the dimensions of the discharge nozzles also affects the nature of the redistribution. It has been established that the relative pressure of the ejector must be taken as equal to its subcritical value when working together with a hydrocyclone.

Author Contributions: Conceptualization, Z.K.; methodologies, Z.K., G.K.; formal analysis, Z.K.; investigation, G.K.; data supervision, Y.K.; writing—drafting, Z.K.; writing—review, G.K.; editing, Z.K.; supervision, Y.K.; funding acquisition, Y.K. All authors have read and agreed to the published version of the manuscript.

Funding: This study was carried out at the Kazakh National Research Technical University named after K.I. Satpayev with the financial support of the Ministry of Education and Science of the Republic of Kazakhstan within the framework of the target program BR 11765599 on the topic “Development and improvement of water treatment technology and improving the quality of drinking water in the regions of Kazakhstan” at 2022–2023. The program includes funds to cover publication costs.

Institutional Review Board Statement: The studies did not include humans or animals.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors are grateful for the support of Satbayev University and the Department of Engineering Systems and Networks for this research work.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Nikolaev, A.G.; Nazarov, S.V.; Chernyshev, M.N. An ejection-type device to increase the self-priming capacity of mobile pumping units. *Sci. Bull. Volsky Mil. Inst. Mater. Support Mil. Sci. J.* **2019**, *3*, 52–54.
2. Kassymbekov, Z.K.; Prutyanova, Y.O. Research of a hydraulic elevator device for lifting pulp from water collection wells. *Water Ecol. Probl. Solut.* **2013**, *2*, 32–39.
3. Urishev, B.U.; Gaimnazarov, I.K. Improving the performance of the pumping unit. *Innov. Dev.* **2017**, *12*, 89–90.
4. Abdreshov, S.A.; Seitassanov, I.S.; Yakovlev, A.A.; Zulpykharov, B.A.; Zhakupova, Z.Z. Technology of water lifting from wells using an improved water jet pump installation. *Int. J. Mech. Prod. Eng. Res. Dev.* **2019**, *9*, 1155–1166.
5. Yakubov, G.G. Improvement of Hydrotransport Systems by Development and Study of Ejection Devices. Ph.D. Thesis, South Ural State University, Chelyabinsk, Russia, 2021; p. 116.
6. Ogorodnikov, S.P.; Mikheev, I.I.; Kulakov, A.E. The use of submersible axial soil pumps is an effective way to increase the suction capacity of dredges. *Min. Inf. Anal. Bull. (Sci. Tech. J.)* **2006**, *8*, 112–116.
7. Arefiev, N.N.; Kuznetsov, S.M. The revised method of calculation of multi-jet ejector design Prof. SP Ogorodnikov. *Proc. Great Rivers Congr.* **2017**, 75.
8. Ukhin, B.V. The use of an ejector at the entrance to vane (soil) pumps. *Min. Inf. Anal. Bull.* **2006**, *S4*, 206–213.
9. Aldiyar, S. The use of ejector and hydrocyclone devices in water supply systems and mini hydroelectric power plants. *Eurasian Sci. Assoc.* **2018**, *5*, 27–29.
10. Pesnia, D.A.; Ryazanov, A.N. Development of the design of a double water jet pump. *Probl. Min.* **2020**, *1*, 262–267.

11. Dik, I.G.; Krokhina, A.V.; Minkov, L.L. Control of hydrocyclone characteristics by additional injection of water. *Theor. Found. Chem. Technol.* **2012**, *46*, 342.
12. Pavlikhin, G.P.; Krokhina, A.V.; Lvov, V.A. Hydrodynamic characteristics of a hydrocyclone with an additional injector. *Saf. Technosphere* **2009**, *6*, 21–25.
13. Ghodrat, M.; Qi, Z.; Kuang, S.B.; Ji, L.; Yu, A.B. Computational investigation of the effect of particle density on the multiphase flows and performance of hydrocyclone. *Miner. Eng.* **2016**, *90*, 55–69. [\[CrossRef\]](#)
14. Dixit, P.; Tiwari, R.; Mukherjee, A.K.; Banerjee, P.K. Application of response surface methodology for modeling and optimization of spiral separator for processing of iron ore slime. *Powder Technol.* **2015**, *275*, 105–112. [\[CrossRef\]](#)
15. Sripriya, R.; Kaulaskar, M.D.; Chakraborty, S. Studies on the performance of a hydrocyclone and modeling for flow characterization in presence and absence of air core. *Chem. Eng. Sci.* **2007**, *62*, 6391–6402. [\[CrossRef\]](#)
16. Kassymbekov, Z.; Akmalaiuly, K.; Kassymbekov, G. Application of Hydrocyclones to Improve Membrane Technologies for Urban Wastewater Treatment. *J. Ecol. Eng.* **2021**, *22*, 148–155. [\[CrossRef\]](#)
17. Zhang, Y.; Yang, M.; Jiang, L.; Wang, H.; Xu, J.; Yang, J. High Concentration Fine Particle Separation Performance in Hydrocyclones. *Minerals* **2021**, *11*, 307. [\[CrossRef\]](#)
18. Hou, D.; Cui, B.; Zhang, H.; Zhao, Q.; Ji, A.; Wei, D.; Feng, Y. Designing the hydrocyclone with flat bottom structure for weakening bypass effect. *Powder Technol.* **2021**, *394*, 724–734. [\[CrossRef\]](#)
19. Saidi, M.; Maddahian, R.; Farhanieh, B.; Afshin, H. Modeling of flow field and separation efficiency of a deoiling hydrocyclone using large eddy simulation. *Int. J. Miner. Process.* **2012**, *112–113*, 84–93. [\[CrossRef\]](#)
20. Bing, L.; Luncao, L.; Huajian, W.; Zhenjiang, Z.; Yaoguang, Q. Numerical simulation and experimental study on internal and external characteristics of novel Hydrocyclones. *Heat Mass Transf.* **2020**, *56*, 1875–1887. [\[CrossRef\]](#)
21. Vakamalla, T.R.; Mangadoddy, N. Numerical simulation of industrial hydrocyclones performance: Role of turbulence modeling. *Sep. Purif. Technol.* **2017**, *176*, 23–39. [\[CrossRef\]](#)
22. Wang, C.; Ji, C.; Zou, J. Simulation and experiment on transitional behaviours of multiphase flow in a hydrocyclone. *Can. J. Chem. Eng.* **2015**, *93*, 1802–1811. [\[CrossRef\]](#)
23. Zhang, Y.; Liu, P.; Ge, J.; Yang, X.; Yang, M.; Jiang, L. Simulation analysis on the separation performance of spiral inlet hydrocyclone. *Int. J. Coal Prep. Util.* **2021**, *41*, 474–490. [\[CrossRef\]](#)
24. Minkov, L.L.; Pikushchak, E.V.; Dik, I.G. Investigation of the influence of water injection on the separation characteristics of a hydrocyclone. *Comput. Res. Model.* **2012**, *4*, 803–810. [\[CrossRef\]](#)
25. Padhi, M.; Kumar, M.; Mangadoddy, N. Understanding the Bicomponent Particle Separation Mechanism in a Hydrocyclone Using a Computational Fluid Dynamics Model. *Ind. Eng. Chem. Res.* **2020**, *59*, 11621–11644. [\[CrossRef\]](#)
26. Vakamalla, T.R.; Mangadoddy, N. The dynamic behaviour of a large-scale 250-mm hydrocyclone: A CFD study. *Asia-Pac. J. Chem. Eng.* **2019**, *14*, e2287. [\[CrossRef\]](#)
27. Li, Y.; Liu, C.; Zhang, T.; Li, D.; Zheng, L. Experimental and numerical study of a hydrocyclone with the modification of geometrical structure. *Can. J. Chem. Eng.* **2018**, *96*, 2638–2649. [\[CrossRef\]](#)
28. Vakamalla, T.R.; Mangadoddy, N. Comprehensive Dense Slurry CFD Model for Performance Evaluation of Industrial Hydrocyclones. *Ind. Eng. Chem. Res.* **2021**, *60*, 12403–12418. [\[CrossRef\]](#)
29. Schuetz, S.; Mayer, G.; Bierdel, M.; Piesche, M. Investigations on the flow and separation behaviour of hydrocyclones using computational fluid dynamics. *Int. J. Miner. Process.* **2004**, *73*, 229–237. [\[CrossRef\]](#)
30. Delgadillo, J.A.; Rajamani, R.K. A comparative study of three turbulence closure models for the hydrocyclone problem. *Int. J. Miner. Process.* **2005**, *77*, 217–230. [\[CrossRef\]](#)
31. Ghodrat, M.; Kuang, S.B.; Yu, A.B.; Vince, A.; Barnett, G.D.; Barnett, P.J. Numerical analysis of hydrocyclones with different conical section designs. *Miner. Eng.* **2014**, *62*, 74–84. [\[CrossRef\]](#)
32. Lamskova, M.I.; Filimonov, M.I.; Novikov, A.E.; Borodychev, S.V. Efficiency and flow characteristics of a hydrocyclone with a filtering drain pipe. *Land Reclam. Hydraul. Eng.* **2021**, *11*, 34–48.
33. Knowles, S.R.; Woods, D.R.; Feuerstein, I.A. Velocity distribution in a hydrocyclone operating without an air core. *Can. J. Chem. Eng.* **2010**, *51*, 263–271. [\[CrossRef\]](#)
34. Lin, Z.; Ma, C.; Xu, H.; Li, X.; Cui, B.; Zhu, Z. Numerical and experimental studies on hydrodynamic characteristics of sleeve regulating valves. *Flow Meas. Instrum.* **2017**, *53*, 279–285. [\[CrossRef\]](#)
35. Liu, H.; Yin, Q.; Huang, Q.; Geng, S.; He, T.; Chen, A. Experimental investigation on interaction of vortex finder diameter and length in a small hydrocyclone for solid-liquid separation. *Sep. Sci. Technol.* **2022**, *57*, 733–748. [\[CrossRef\]](#)
36. Gonçalves, S.M.; Ullmann, G.; Morimoto, M.G.; de Souza Barrozo, M.A.; Vieira, L.G.M. Effect of rheology and solids concentration on hydrocyclones performance: A study involving the design variables of an optimized hydrocyclone. *J. Pet. Sci. Eng.* **2022**, *210*, 110019. [\[CrossRef\]](#)
37. Chu, L.Y.; Chen, W.M.; Lee, X.Z. Enhancement of hydrocyclone performance by controlling the inside turbulence structure. *Chem. Eng. Sci.* **2002**, *57*, 207–212. [\[CrossRef\]](#)
38. Neesse, T.; Dueck, J.; Schwemmer, H.; Farghaly, M. Using a high pressure hydrocyclone for solids classification in the submicron range. *Miner. Eng.* **2015**, *71*, 85–88. [\[CrossRef\]](#)
39. Matvienko, O.V.; Andropova, A.O. Investigation of the effect of hydrocyclone outflow regimes on its separation characteristics. *Eng. Phys. J.* **2014**, *87*, 23–34.

-
40. Sabbagh, R.; Lipsett, M.G.; Koch, C.R.; Nobes, D.S. An experimental investigation on hydrocyclone underflow pumping. *Powder Technol.* **2017**, *305*, 99–108. [[CrossRef](#)]
 41. Zou, J.; Wang, C.; Ji, C. Experimental study on the air core in a hydrocyclone. *Dry. Technol.* **2016**, *34*, 854–860. [[CrossRef](#)]
 42. Ullmann, G.; Gonçalves, S.M.; Kyriakidis, Y.N.; de Souza Barrozo, M.A.; Vieira, L.G.M. Optimization study of thickener hydrocyclones. *Miner. Eng.* **2021**, *170*, 107066. [[CrossRef](#)]
 43. Vega-Garcia, D.; Brito Parada, P.; Cilliers, J.J. Optimising small hydrocyclone design using 3D printing and CFD simulations. *Chem. Eng. J.* **2018**, *350*, 653–659. [[CrossRef](#)]
 44. Zhang, Y.; Ge, J.; Jiang, L.; Wang, H.; Yang, J.; Chen, B. Influence of Vortex Finder Structure on Separation Performance of Double-Overflow Three-Product Hydrocyclones. *Separations* **2021**, *8*, 79. [[CrossRef](#)]
 45. Abduramanov, A. *Hydraulics of Hydrocyclones and Hydrocyclone Pumping Units*; Publishing House Academy of Natural History: Penza, Russia, 2018; 240p.
 46. ESU-20 Downhole Ejector Unit. Available online: <http://www.drillings.ru/esuas> (accessed on 15 June 2021).