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RESEARCH ARTICLE

RESEARCH ON HYDROCYCLONIC PURIFICATION OF THE HEAT TRANSFER FLUID TO IMPROVE THE OPERATING MODE OF THE CIRCULATION PUMP

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Abstract. *Contamination of the heat carrier is the primary cause of premature wear and reduced performance of the circulation pump. Abrasive particles, scale, and sludge lead to the abrasion of ceramic bearings, rotor blockage, and cavitation. Clogging of suction filters results in a sharp pressure drop, which induces vapor formation and subsequent destruction of pump blades. Therefore, implementing advanced filtration methods helps stabilize the hydraulic regime and extend equipment service life. The objective of this study is to investigate the feasibility of applying the hydrocycloning effect to remove impurities and sludge both upstream and downstream of the circulation pump, as a replacement for the conventional mesh strainer (mud trap), by employing a combined pressure-vacuum operating mode. Methodologically, the main parameters of the developed hydrocyclone device were determined by testing its modular prototype on a specially constructed experimental stand. The functional characteristics of two-phase fluid flow inside the hydrocyclone were established through computer simulation using the SOLIDWORKS Flow Simulation module. The study revealed the flow velocity profiles under both pressure and vacuum operating modes of the hydrocyclone. The inlet velocity values ranged between 2.8-4.2 m/s, and subsequently increased to 4.9 m/s in the cylindrical-conical section due to water circulation. Sediments entering the hydrocyclone with an initial particle size of 0.1-0.5 mm were fully captured, while only particles smaller than 0.1 mm passed through the drain pipe. The possibility of removing captured impurities from the outlet section in vacuum mode, aided by an ejector, enhances the apparatus's water purification capacity.*

Keywords: *hydrocyclone, heat transfer fluid purification, pressure-vacuum mode, laboratory test rig, circulation pump, testing.*

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ҒЫЛЫМИ МАҚАЛА

АЙНАЛЫМ СОРАБЫНЫҢ ЖҰМЫС ТӘРТІБІН ЖАҚСАРТУ ҮШІН ЖЫЛУ ТАСЫҒЫШТЫ ГИДРОЦИКЛОНДЫҚ ТАЗАРТУДЫ ЗЕРТТЕУ

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Аңдатпа. *Жылу тасымалдағыштың ластануы мерзімінен бұрын тозуының және айналым сорабының өнімділігінің төмендеуінің басты себебі болып табылады. Абразивтік бөлшектер, қайнатпа және шлам керамикалық мойынтіректердің сүртілуіне, ротордың бұғатталуына және кавитацияға әкеледі. Сораптағы сүзгілердің бітелуі қысымның күрт төмендеуіне әкеледі, бұл сорап қалақтарының буға айналуына және бұзылуына әкеледі. Сондықтан фильтрациялаудың перспективалық әдістерін енгізу гидравликалық режимді тұрақтандыруға және жабдықтың қызмет ету мерзімін ұзартуға мүмкіндік береді. Осы жұмыстың мақсаты қысымды-вакуумдық жұмыс режимін құру есебінен қолданыстағы торлы сүзгі-балшық орнына айналым сорабына дейін және одан кейін қоспалар және шламды тазарту кезінде гидроциклондау әсерін қолдану мүмкіндігін зерделеу болып табылады. Әдістемелік жоспарда әзірленген гидроциклондық құрылғының негізгі параметрлері оның модульдік үлгісін арнайы жасалған стендте сынаумен айқындалды. Гидроциклон ішіндегі екі фазалы сұйықтық ағынының функционалдық өзгерістерінің сипаты SOLIDWORKS Flow Simulation модулін қолдану арқылы процесті компьютерлік модельдеу жолымен белгіленді. Зерттеу нәтижесінде гидроциклонның қысымды және вакуумдық режимдегі жұмысы кезіндегі ағын жылдамдығының профелі анықталды. Кіре берістегі жылдамдықтың белгіленген мәндері 2,8-4,2 м/с шегінде өзгерді, содан кейін цилиндрлік-конустық бөлігінде су айналымының есебінен 4,9 м/с дейін көтерілді. Бастапқы іріліг 0,1-0,5 мм болатын гидроциклонға түсетін шұңқырлар толық ұсталады. Құю келте құбыры арқылы диаметрі 0,1 мм кем бөлшектер ғана өтеді. Эжектор көмегімен вакуумдық режимде ұсталатын қоспаларды саға бөліктен шығару мүмкіндігі аппараттың су тазалау қабілетін арттырады.*

Түйін сөздер: *гидроциклон, жылу тасығышты тазалау, қысымды-вакуумдық режим, зертханалық стенд, айналым сорабы, сынау.*

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НАУЧНАЯ СТАТЬЯ

ИССЛЕДОВАНИЕ ГИДРОЦИКЛОННОЙ ОЧИСТКИ ТЕПЛОНОСИТЕЛЯ ДЛЯ УЛУЧШЕНИЯ РЕЖИМА РАБОТЫ ЦИРКУЛЯЦИОННОГО НАСОСА

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Аннотация. *Загрязнение теплоносителя является главной причиной преждевременного износа и снижения производительности циркуляционного насоса. Абразивные частицы, накипь и шлам приводят к истиранию керамических подшипников, блокировке ротора и кавитации. Засоры фильтров на всасывании вызывают резкое падение давления, что приводит к парообразованию и разрушению лопастей насоса. Поэтому внедрение перспективных методов фильтрации позволяет стабилизировать гидравлический режим и продлить срок службы оборудования. Целью настоящей работы является изучение возможности применения эффекта гидроциклонирования при очистке примесей и шлама до и после циркуляционного насоса, взамен существующего сетчатого фильтра-грязевика, за счет создания напорно-вакуумного режима работы. В методическом плане основные параметры разработанного гидроциклонного устройства определялись испытанием его модульного образца на специально построенном стенде. Характер функциональных изменений течения двухфазной жидкости внутри гидроциклона устанавливался путем компьютерного моделирования процесса с применением модуля SOLIDWORKS Flow Simulation. В результате исследования выявлены профили скоростей потока при работе гидроциклона в напорном и вакуумном режимах. Установленные значения скорости на входе варьировались в пределах 2,8-4,2 м/с, а затем в цилиндро-конической части за счет циркуляции воды повышались до 4,9 м/с. Наносы, поступающие в гидроциклон с исходной крупностью 0,1-0,5 мм, улавливаются полностью. Через сливной патрубок проходят только частицы диаметром менее 0,1 мм. Возможность удаления улавливаемых примесей из устьевой части при вакуумном режиме с помощью эжектора повышает водоочистную способность аппарата.*

Ключевые слова: *гидроциклон, очистка теплоносителя, напорно-вакуумный режим, лабораторный стенд, циркуляционный насос, испытание.*

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1 INTRODUCTION

In district heating systems, circulation pumps play a particularly important role by transporting the heat transfer medium (water). However, for decades, the dominant technology was non-variable-speed pumps operating at a constant speed, which led to significant energy wastage and pipe wear [17; 26]. Large-scale studies show that pumping equipment accounts for up to 10-15% of the world's total electricity generation [15].

The switch to variable-speed drive (VSD) pumps has been a significant step forward. The variable-speed drive allows the pump's output to be adjusted flexibly in line with the actual load and delivers energy savings of up to 40-50% [9; 12].

The results of using variable-speed drives in heating systems and the effectiveness of their implementation are outlined in scientific articles [18; 29]. As stated in these, the reduction in energy consumption is achieved by precisely adjusting the motor speed to the required load, rather than using valves or throttles. The high efficiency of the inverters (on average, around 98%) ensures that the device itself does not become a significant source of losses.

The findings of a research study [21] clearly demonstrate that, in water supply systems with variable loads, the use of a control law based on the hydraulic resistance curve results in 18-22% higher seasonal energy efficiency. In the context of heating systems, there is growing interest in combined and hybrid strategies. A study [7] proposes an adaptive algorithm that dynamically switches between control modes depending on the rate of change in outdoor temperature and the operating mode of the heat distribution unit, enabling additional energy savings of 8-12%.

The approach outlined in the paper [19] is being further developed in studies that build predictive models using machine learning methods [5] and employ recurrent neural networks (RNNs) for ultra-short-term forecasting of neighborhood thermal loads. Integrating this model into the pump control system has reduced peak electricity consumption at pumping stations in hydraulic structures by 15% [3]. The authors of the paper [11] proposed a digital twin architecture in which Gaussian process regression (GPR) is used to model an industrial heat pump during energy recovery.

The study [13] focuses on the control of pumps in buffer storage water heaters in combination with photovoltaic systems. The algorithm shifts pump operation to periods of peak solar generation, thereby increasing self-consumption and reducing grid load. This approach, known as demand-side management, transforms the pump from a passive consumer into an active element of the smart grid.

The potential of data collected from modern pumps is explored in studies [6; 8; 30] on predictive maintenance and data analysis. Using anomaly detection algorithms, this system can predict the onset of failures such as impeller wear or seal failure within 30-70 hours, significantly reducing repair costs and downtime.

As is well known from practical experience, heating systems require the coolant to be cleaned [2]. To reduce failures and wear and tear, the use of more effective cleaning technologies is envisaged in virtually all cases [10]. This helps to extend the service life of heating equipment and improve heating efficiency and energy utilization [22].

The heating system uses several types of filters, the most essential of which is the coarse filter, commonly known as a 'mud trap'. These filters are typically installed on the return pipe upstream of the heater and pump to trap any accumulated debris before it enters the heater. The technical and operational parameters are selected based on the degree of contamination, the consistency of the heat transfer fluid, and the operating temperature and supply pressure [24].

A drawback of standard water treatment systems, which consist of various types of strainer filters used in recirculating water supply systems in heating plants and domestic heating systems, is their inability to achieve the required level of water purification from mechanical impurities and suspended solids, which strainer filters fail to capture at all [25]. Furthermore, the devices themselves require constant cleaning during operation. Other drawbacks include the inability to filter out fine particles (smaller than 400-500 microns) and the need to shut off the water supply to remove the plug and clean the mesh.

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The operating principle of a separator-type sludge trap is based on a combination of two processes: inertia and gravity [2; 32]. Combining the processes of inertia and gravity significantly increases the degree of water purification from mechanical impurities compared with existing standard sedimentation tanks and yields substantial economic benefits from implementing this apparatus [4]. One prospective option for a separation-type water purifier is the use of pressure and vacuum hydrocyclones [1; 31]. In vacuum hydrocyclones, unlike pressure hydrocyclones, the separation of the two-phase liquid occurs due to artificial rarefaction (vacuum), as they are located on the suction line of the centrifugal pump [16; 28]. As a result, mechanical impurities do not enter the pump impellers, thereby providing protection against abrasive wear.

The aim of this study is to investigate the possibility of using this technological effect to remove impurities and sludge upstream of the circulation pump, as a replacement for the existing strainer.

2 MATERIALS AND METHODS

Figures 1 and 2 show the structural scheme and general view of the laboratory test rig used to investigate a hydrocyclone device for purifying heat-transfer fluid (contaminated water). It consists of a tank 1, a centrifugal pump 2, a gate valve for regulating the water supply 3, a flow meter for measuring the volume of water supplied 4, and 5 a pressure gauge for measuring the working pressure entering the hydrocyclone 6.

The test rig's operating principle is as follows. When pump 1, located on the surface, is switched on, water is fed under pressure through flow meter 4 into hydrocyclone 6. The tangential entry of water into the hydrocyclone creates a swirling flow, and centrifugal force causes the solid particles to separate from the liquid. In the chosen scheme, the hydrocyclone operates in pressurized mode; therefore, the captured solid particles are carried out through the sand outlet into the discharge chute by residual pressure. The purified water is returned to tank 1 via another flow meter. This creates a closed-loop system for the purification and reuse of process water. It also ensures the continuity of the device's operation. If it is necessary to increase the concentration of solids in the liquid, the captured impurities are also fed into the tank via the lower pipe of the hydrocyclone.

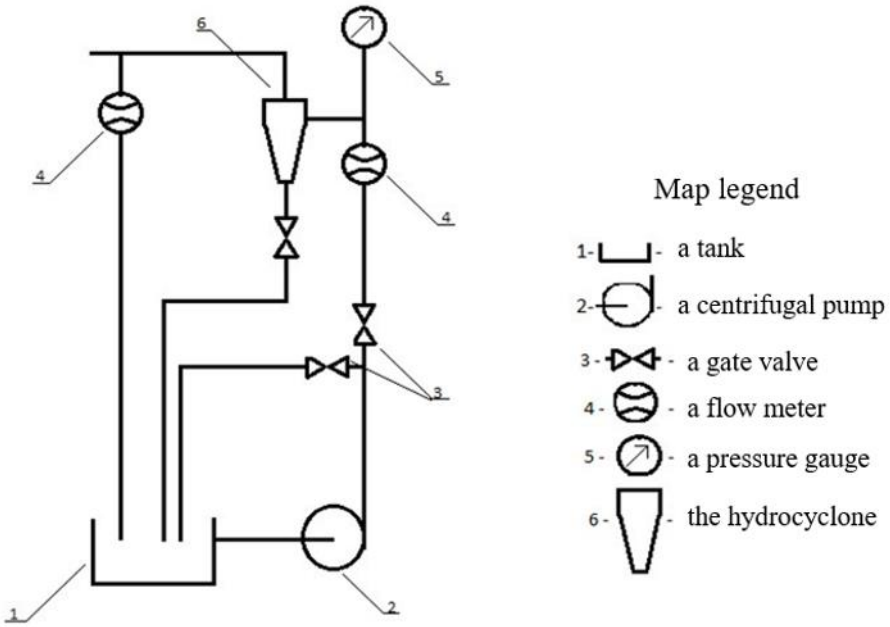


Figure 1 - Diagram of a laboratory test rig for investigating a hydrocyclone (references in the text) [Author's material]

The main equipment and nodes used for the study have the following dimensions and parameters. The cylindrical-conical hydrocyclone has a diameter of Dc = 50 mm and a height of Hc = 220

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mm. It is mounted on the test rig panel in a vertical position. The QB 60 vortex centrifugal pump can deliver a water flow rate of up to 40 l/min and a pressure of 40 m. The water tank has a capacity of 25 liters. The SGV-1.5 flow meter is rated for a maximum flow rate of Q = 1.5 m³/h. The reference pressure gauge can display an operating pressure up to P = 600 kPa.



Figure 2 - General view of the laboratory test rig [Author's material]

The acceptable designs and corresponding grades of the test rig components listed above were adopted based on the approved technical specifications and requirements for water treatment equipment, the reviewed schematics, and the technical justification for water treatment.

According to its technical specifications, the QB series vortex centrifugal pump Figure 3a is designed to supply liquid from various water sources and can operate in automatic modes, including those with variable-frequency control.

Due to the design features of the impeller, pumps in this class are capable of efficiently transferring not only clean water but also certain gas-liquid mixtures containing insoluble particles at concentrations of between 0.01% and 0.02%. They also offer the following advantages:

higher pressure at the outlet compared to other models;

low sensitivity to air bubbles in the liquid;

self-priming capability;

simple design and ease of maintenance;

A pressure hydrocyclone Figure 3b is used in heating systems to mechanically remove scale, sand, sludge, and rust from make-up water, mains water, and condensate, thereby extending the service life of pumps, heaters, and heat exchangers. It does not require the constant replacement of screens or cartridges, as with strainer filters, and it can withstand high temperatures and pressures.

A liquid flow meter Figure 3c measures the instantaneous flow rate of the liquid passing through the pipeline per unit time. Liquid flow meters also allow the total volume of liquid that has passed through the device over a specific period of time (from the start of the reading) to be determined, whilst measuring the instantaneous flow rate.

The operating principle of the pressure gauge Figure 3d is based on balancing the measured pressure with the force of elastic deformation of a tubular spring or a more sensitive two-plate diaphragm, one end of which is sealed into a holder, whilst the other is connected via a linkage to a sector-and-pinion mechanism that converts the linear movement of the elastic sensing element into the circular motion of the indicator pointer.

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The working pressure gauge used corresponded to accuracy class 1.5.

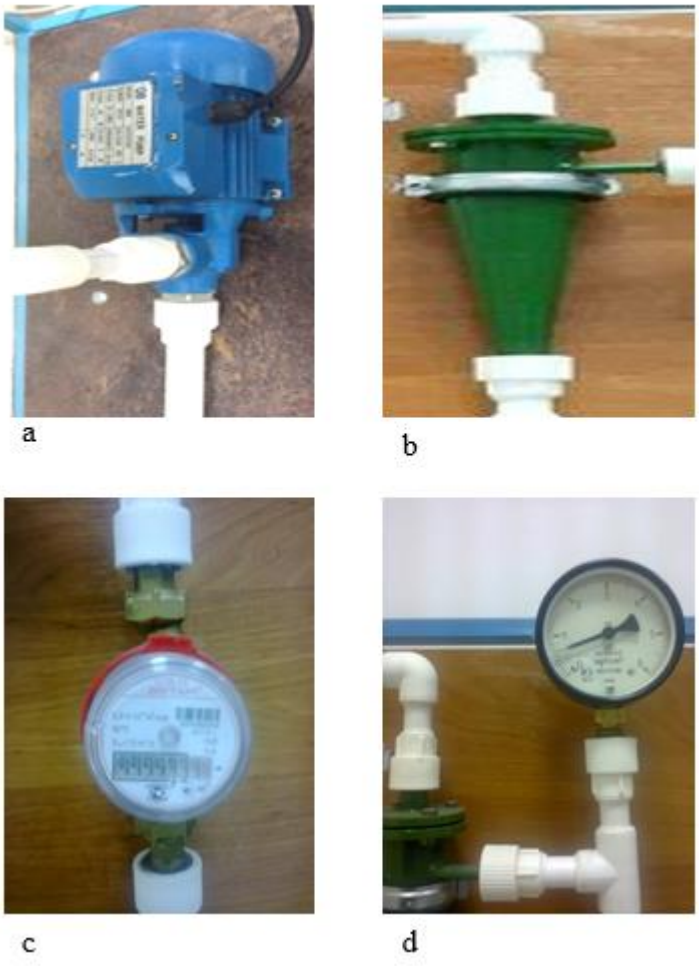


Figure 3 - Approved designs and relevant specifications for the test rig components listed above a) centrifugal pump, b) hydrocyclone, c) flow meter, d) pressure gauge [Author's material]

The main aim of the experiment was to study the flow-pressure characteristics and efficiency of the hydrocyclone under various operating conditions. To do this, the tank is first filled with water whilst the valves are closed. The pump is then switched on and runs at no-load mode for 5-10 minutes.

Once the no-load mode ends, the gate valve at the hydrocyclone inlet opens, and water enters the hydrocyclone tangentially through the feed pipe. The water is purified within the hydrocyclone, i.e., the solid phase is separated from the liquid. At this point, the readings on the flow meters and the pressure gauge are recorded.

A total of three independent experimental series were conducted, with each measurement repeated three times. The data are presented with the standard deviation (SD), and the confidence interval was set at 95% ($p<0.05$). In the tables and graphs, the obtained parameters are reported with consideration of the arithmetic deviation (SD).

Preliminary data indicate that, once the hydrocyclone chamber has reached steady-state operation, an increase in the initial pressure P leads to an increase in the liquid flow rate Q, which, under operating conditions, reaches the value of the base pump [14; 20].

The calculated flow rate of purified water through the drain pipe is verified using the following formula. Due to limitations in the test rig's actual parameters, the unit of measurement is subsequently converted to liters per minute (L/min).

$$Q = k_1 \times d\sqrt{2q \times \Delta H}\,, m^3/s \quad (1)$$

where:

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k_1 – a coefficient that takes into account the parameters and operating mode of the hydrocyclone, k_1 = 18.0-22.0;
d – the diameter of the hydrocyclone discharge pipe, m;
H – the head loss in the hydrocyclone, m.

The degree of water purification in a hydrocyclone, which characterises the efficiency of separating mechanical impurities:

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

where:
Q_2^1 – the flow rate of sand through the outlet pipe, m³/s;
Q_1 – the flow rate of water through the inlet pipe, m³/s.

3 RESULTS AND DISCUSSION

3.1. Analysis of laboratory test results under various operating modes

At the start of the laboratory test rig, the processes involved in the redistribution of water fed into the hydrocyclone between the unit's discharge and sand outlets were examined. The discharge outlet is the upper pipe, from which the purified water exits, whilst the sand outlet is the lower pipe (opening) through which the concentrated sand mass is discharged. The cross-sections of these, i.e., the inlet and outlet of the liquid through the specified openings, were adjusted using gate valves.

It turned out that when the sand trap opening was half-open (d = 7.5 mm), the incoming water flowed predominantly through the sand trap, whereas when the opening was set to d = 3.5 mm, the flow of purified water through the drain pipe returned to normal. A total of 5 valve positions were examined. The readings obtained from the instruments (pressure gauge, flow meter, stopwatch) are shown in Table 1.

Table 1 - Qualitative and quantitative parameters of a hydrocyclone when the cross-sectional area of the discharge ports is varied [Author's material]

№	Inlet pressure at the hydrocyclone, P, kPa	Basic water volume, l	Water volume reading during the experiment, l	Operating time, min	Total water flow rate, Q l/min
1	10	44.0	33.75	4.5	7.5
2	20	60.0	45.50	4.5	10.0
3	40	90.0	68.85	4.5	15.3
4	60	96.0	74.25	4.5	16.5
5	80	112.0	90.00	4.5	20.0

Based on the above results of the studied process, the following graph, Q = f(P), was plotted to illustrate the relationship between the main parameters Figure 4.

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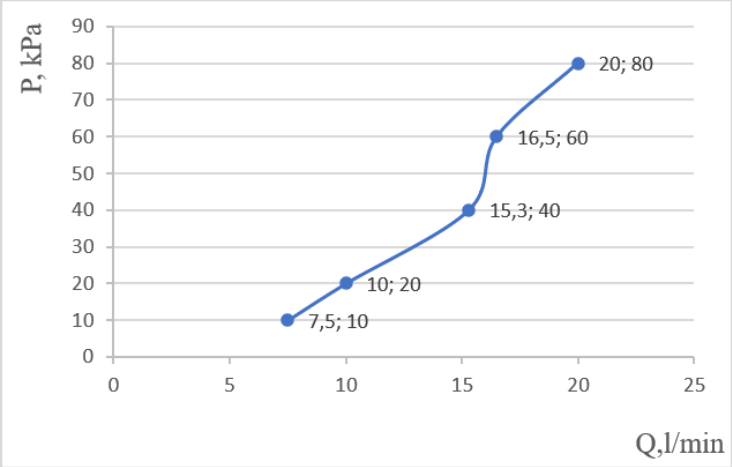


Figure 4 - Graphical representation of Q as a function of P with the sand vent open [Author's material]

Following these tests, the purification processes were examined; the performance characteristics of the hydrocyclone unit in the water treatment system with the sand outlet closed are shown in Table 2 and Figure 5.

It turned out that maintaining the original diameter of the drain pipe whilst the sand trap is closed increases the volume of water flowing into the drain. An increase in inlet pressure increases flow velocity, thereby increasing centrifugal forces. This redistributes the flow in favor of the drain.

Table 2 - Results of the study of the working characteristics of the hydrocyclone water treatment unit with the sand outlet closed [Author's material]

№	Inlet pressure at the hydrocyclone, P, kPa	Basic water volume, l	Water volume reading during the experiment, l	Operating time, min	Total water flow rate, Q l/min
1	20	60.0	54.0	4.5	12
2	40	69.0	63.0	4.5	14
3	60	81.0	72.0	4.5	16
4	80	96.0	88.7	4.5	19.7

When the hydrocyclone's lower (sand) outlet is completely closed, and the unit is operating in sedimentation mode, a sand cushion forms at the sand outlet. If the concentration of the initial contaminated liquid increases further in other cases, the separation of fractions ceases, and the unit operates as a transit mixer, discharging the entire mass (both liquid and solid particles) through the upper discharge pipe.

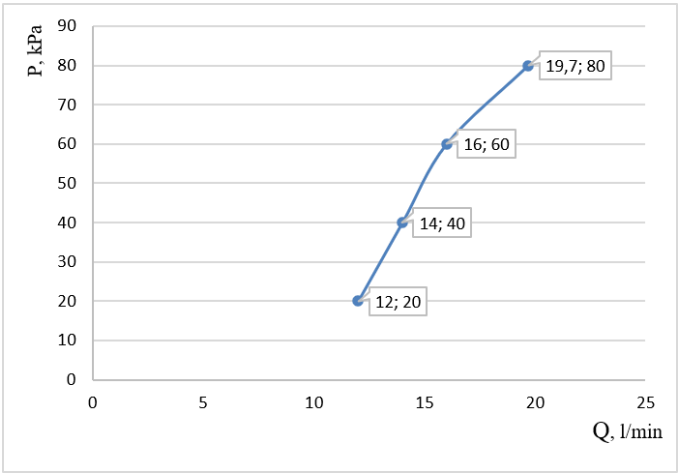


Figure 5 - Graphs of Q as a function of P with the sand vent closed [Author's material]

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3.2. Analysis and evaluation of functional changes in the flow of a two-phase fluid within a hydrocyclone

The analysis and evaluation of the functional changes in the two-phase fluid flow within the hydrocyclone during testing were performed using computer modeling with the SOLIDWORKS Flow Simulation module [27]. This is because the parameters of interest within the hydrocyclone cannot be measured directly with instruments, and this module enables the desired hydrodynamic flow effects to be modeled quickly and easily. The description of swirling two-phase turbulent flows was carried out using the Reynolds equation for mixtures and the equation for the change in the volume fraction of particles. The k–ε–RNG turbulence model was used to determine the mixture turbulence parameters. It has been confirmed that the Reynolds stress model is the best choice for multiphase modeling of swirled flow in hydrocyclones on relatively coarse grids.

The flow velocity profiles in a hydrocyclone with an integrated ejector are examined using three-dimensional hydrodynamic modeling that accounts for the assumed turbulence [23].

The following assumptions were made when formulating the mathematical and numerical models: changes in the flow pressure and temperature within the hydrocyclone are negligible, and the mesh sizes are comparable to the simulated droplet sizes. The geometry and boundary conditions were based on the hydrocyclone's design and manufacturing parameters for the selected diameter. The results of the computer simulations of flow patterns for the selected module are shown in Figures 6 and 7, which were generated using the simulation boundary conditions (Tables 3-5).

The simulation results for water intake using a vacuum hydrocyclone without an additional filter are shown below. In the calculations, the amount of sediment (sand) with different particle sizes at the hydrocyclone inlet was assumed to be 100 units (Table 3).

Table 3 –The calculated number of sediment fed into the hydrocyclone during the simulation [Author's material]

Diameter of the sediment fraction (mm)	< 0.01	0.01-0.05	0.05-0.1	0.1-0.25	0.25-0.5	> 0.50	Total
Number of sediment, pcs	100	100	100	100	100	100	600

The calculated results and particle-size and velocity-distribution profiles for the modeling variant under consideration, at various feed rates and sand diameters, are presented in Tables 4-5.

The data in the tables show that the suction pipe, via the hydrocyclone drain, primarily receives sediment (sand) with particle sizes between 0.01 and 0.1 mm, which accounts for 58% of the total volume of the finest sediment (<0.01 mm).

Table 4 – Estimated volume of sediment passing through the drain pipe at maximum water flow (option 1) [Author's material]

At a maximum water flow rate through the drain of 20.0 l/min							
Diameter of the sediment fraction (mm)	<0.01	0.01-0.05	0.05-0.1	0.1-0.25	0.25-0.5	> 0.50	Total out of 600
Number of missed sediment out of 100, at the drain	42	36	24	0	0	0	102

This will fully meet the project specifications (a reduction in turbidity of at least 30%).

Table 5 – Estimated volume of sediment passing through the drain pipe at minimum water flow (option 2) [Author's material]

With an average water flow rate through the drain of 14 litres per minute							
Diameter of the sediment fraction (mm)	<0.01	0.01-0.05	0.05-0.1	0.1-0.25	0.25-0.5	> 0.50	Total out of 600
Number of missed sediment out of 100, at the drain	25	21	15	0	0	0	61

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As shown by the flow velocity profiles during the operation of the hydrocyclone in pressure mode, the velocity at the inlet ranges from 2.8 to 4.2 m/s, then rises to 4.9 m/s in the cylindrical-conical section due to water circulation Figure 6.

The trajectory of the sediment (sand) and its distribution within the hydrocyclone under the water intake conditions from the water source under consideration are shown in Figure 7.

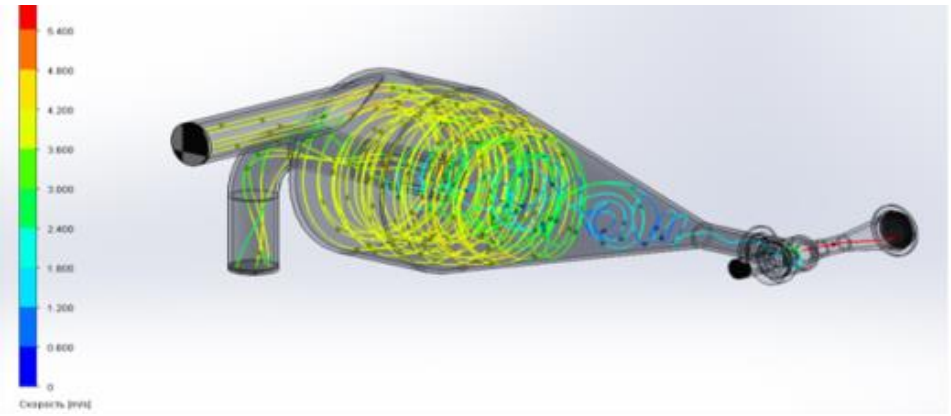


Figure 6 - Flow velocity profile when the hydrocyclone is operating without a filter [Author's material]

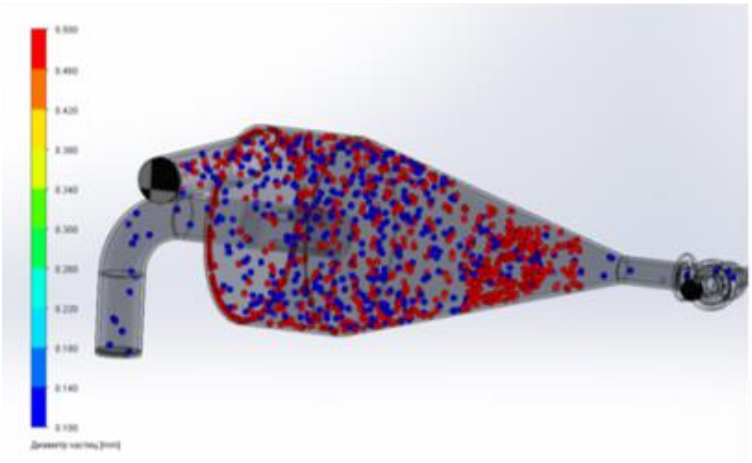


Figure 7 - Distribution of sediment (sand) within the hydrocyclone [Author's material]

As shown in Figure 7, the sediment entering the hydrocyclone with an initial particle size between 0.1 and 0.5 mm is captured in its entirety, consistent with the calculated data. Only particles with diameters below 0.1 mm pass through the discharge pipe. Larger particles (0.3-0.5 mm) are pressed against the wall of the hydrocyclone by centrifugal forces and transported along a downward spiral into the lower flow at the sand outlet. The results of the computer simulation of the process in a vacuum hydrocyclone with an ejector are shown in Table 6 and in Figures 8 and 9.

Table 6 – Estimated volume of sediment passing through the drain pipe at maximum water flow (option 4) [Author's material]

Outlet water flow rate - 20.0 l/min							
Diameter of the sediment fraction (mm)	<0.01	0.01-0.05	0.05-0.1	0.1-0.25	0.25-0.5	> 0.50	Total out of 600
Number of missed sediment out of 100, at the drain	35	31	0	0	0	0	66

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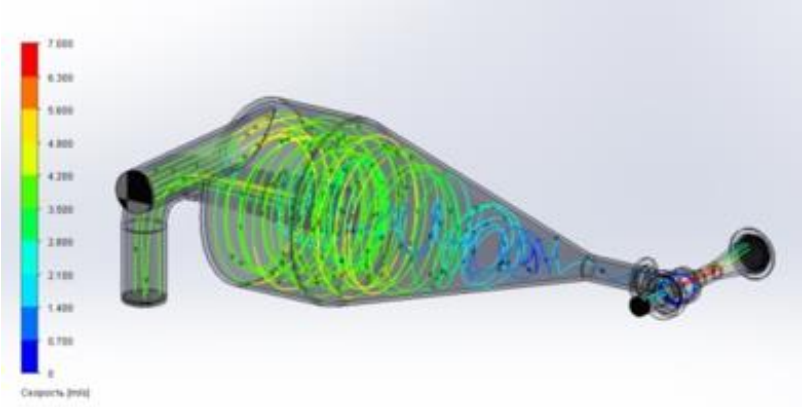


Figure 8 - Flow velocity profile during operation of a side-entry hydrocyclone [Author's material]

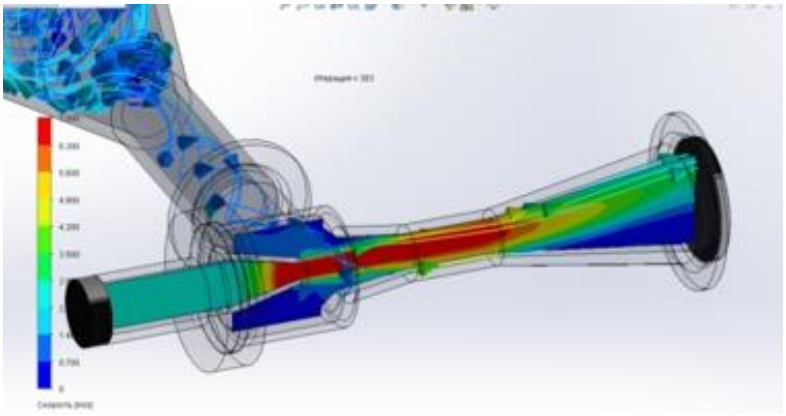


Figure 9 - The moment when the concentrated slurry is ejected from the sand outlet of the hydrocyclone into the discharge chute [Author's material]

The experimental data show that continuously removing residual impurities from the hydrocyclone's outlet section using an ejector improves the unit's water treatment capacity and, ultimately, the performance of the new water intake facility.

4 CONCLUSIONS

The results of the study confirm that hydrocyclonic purification of the heat-transfer fluid should be considered an effective technological alternative to conventional mesh-strainer filters in circulation pump systems. Based on the conducted analysis, the following conclusions can be drawn.

1. In order to reduce the number of failures and instances of wear and tear in heat transport lines and equipment, it is necessary in almost all cases to employ more effective heat transfer fluid purification technologies.

2. A drawback of the water treatment methods currently in use which consist of various types of strainer filters in recirculating water supply systems is that they fail to achieve the required level of purification of water from mechanical impurities, as well as suspended solids, which strainer filters do not capture at all.

3. It is proposed to replace the mesh strainers with cylindrical-conical hydrocyclones, which are capable of operating in both pressure and vacuum modes. This flexibility allows them to be installed either on the suction line of the circulation pump or downstream of it, depending on the specific layout of the water treatment system.

4. The test results show that, once the hydrocyclone chamber has reached steady-state mode, an increase in the initial pressure P leads to an increase in the flow rate of the purified liquid through the drain Q.

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5. Computer modeling of the process using the SOLIDWORKS Flow Simulation module was employed to analyze and evaluate the functional changes in the flow of a two-phase fluid within a hydrocyclone.

6. As can be seen from the flow velocity profiles plotted for the hydrocyclone operating in pressure mode, the velocity at the inlet ranges from 2.8 to 4.2 m/s, and then rises to 4.9 m/s in the cylindrical-conical section due to water circulation. Sediment entering the hydrocyclone with an initial particle size of 0.1-0.5 mm is fully captured, which corresponds to the design data. Only particles with diameters below 0.1 mm pass through the discharge pipe. Larger particles (0.3-0.5 mm) are transported along the downward spiral into the lower flow near the sand outlet.

7. The ability to remove captured impurities from the outlet section under vacuum mode using an ejector improves the unit's water purification capacity.

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The authors state that there is no conflict of interest.

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