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ИЗВЕСТИЯ

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РЕСПУБЛИКИ КАЗАХСТАН
Satbayev University

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DEVELOPMENT AND TESTING OF A HYDROCYCLONE SAND TRAP FOR MINI HPP

Abstract. The goal of the project is to develop and use a hydrocyclone sand trap to improve the operation of a mini hydroelectric power station. In contrast to the existing design of a similar type of hydroelectric power station, a bulky sump for water purification has been replaced with an efficient hydrocyclone device. Due to this, a simplification of the design of the HPP is achieved, an increase in the degree of sand collection from the composition of the water used.

Research methods. The initial data for the calculation were taken: the flow rate of water passing through the hydrocyclone and the pressure drop at the inlet and outlet of the hydrocyclone. Computer simulation of the process was carried out using the SolidWorks software (flow simulation). The main technological parameters and a rational mode of operation were established by testing experimental samples both in laboratory and in production conditions.

Research results. In the established mode, the density of clarified water is equal to 1.009 ... 1.050 t / m^3, and the degree of purification is 91 ... 97%. Replacing a bulky reinforced concrete sump with hydrocyclone sand traps of a simplified design reduces the cost of building a water treatment unit from 30% (existing) to 7%. This makes it possible to expand the volume of development of small hydroelectric power plants, especially in mountainous conditions.

Key words: mini hydroelectric power station, development, hydrocyclone sand trap, process modeling, experimental stand, tests.

Introduction. It is well known that hydropower is the most widespread in practice and technologically advanced industry in renewable energy sources [1-6].

Unlike other ecologically safe renewable sources such as the sun, wind, small hydropower practically does not depend on weather conditions and capable to provide steady supply of the cheap electric power to the consumer.

Articles [7-9] show that broad prospects are revealed before small (100 - 1000 kW) and mini-hydroelectric plants (up to 100 kW), especially when using them in foothill and mountain regions. The efficiency of such a power plant can significantly increase if it is used in conjunction with other types of renewable sources, for example, wind power or solar power plants.

As operation experience of a hydroelectric power station demonstrates, the technical condition and reliability of hydroturbine equipment affect the efficiency of their operation, especially the power characteristic [9-12]. In the presence of mechanical impurities in the feed water, hydraulic units are often subjected to abrasive wear. Abrasive wear of turbines leads to a significant drop in their efficiency, and consequently, to a decrease in the power and power output of a hydroelectric power station, to a reduction in the service life of hydro turbine equipment [13-18].

In the widespread derivational schemes of hydroelectric power stations, the protection of hydraulic units from bottom and bottom sediments is carried out in water receivers, and purification of water from hazardous fractions of mechanical impurities is carried out in sedimentation tanks.

In common HES derivation schemes, the protection of hydraulic units from bottom and bottom sediments is carried out in water intakes, and the water is cleaned from dangerous fractions of mechanical impurities in septic tanks [5,19].

However, the cost of the construction of the sump, due to its cumbersome design, are very significant and sometimes make up 20-35% of the investment in the construction of a hydropower plant [19].

These problems to reduce capital investments in construction and the cost of operating a hydropower plant, in our opinion, can be eliminated by using the energy of the watercourse through the diversion channel (pipeline) to separate mechanical impurities from water using hydrocyclones. In this case, the construction of bulky settlers is no longer necessary [2].

Description of the development and research methods. The developed mini hydroelectric power station (HPP) includes a hydrocyclone sand trap, a water treatment unit, a diversion unit, a canal, a hydro-electric power station, a hydro turbine, a generator, a hydrocyclone and a suction pipe (figures 1 and 2) [19].

Figure 1 – Technological scheme of mini HPP with hydrocyclone

Figure 2 – General view of the developed hydrocyclone sand trap

The sand collection unit (figure 2) consists of hydrocyclones with receiving chambers and a drain pipe, a viewing well, a viewing channel pan, a sand pipe and a ladder. The threshold, installed inside the diversion channel, is provided in order to ensure the complete flow of water with mechanical impurities into the inlet chamber of the hydrocyclone.

When a hydropower plant is in operation, water with mechanical impurities, moving at the expense of the velocity head in the channel, gets tangentially into the hydrocyclone and is cleared of solid components. Purified water through the upper drain pipe, located in the direction of flow of fluid, flows back into the channel and is fed to the working nozzles of the turbine. Mechanical impurities captured in a hydrocyclone, mainly in the form of fine sand with diameters greater than 0.05 mm, are ejected into a heap by a sand extraction pipe.

The height of the sand mass accumulation at the sand hole within 1/3 of the height of the conical part of the hydrocyclone and the opening of the sand removal line is adjusted using an automatic controller of a simple action.

The initial data for the calculation of a hydro-cyclone unit of a small hydroelectric station are taken: the flow of water passing through the hydro-cyclone - Qn and the pressure drop at the entrance to the hydro-cyclone and its output - Nn, as well as the content of suspended particles before cleaning - γ. [21].

Based on the results of the analysis, it was revealed that in order to use computer simulation data, the numerical model must be verified by a physical experiment. Therefore, numerical analyzes of the processes were carried out on the basis of the STAR CCM + 6.04 software package using the results of experimental studies.

This study includes the calculation of the flow lines of the velocity of particles of a liquid in a hydrocyclone, the trajectory of movement of solid particles, pressure drop, and the efficiency of separation of liquid and solid particles.

For the numerical calculations of this problem, the geometry was chosen with the following characteristics:

1. Dimensions of the hydrocyclone: the area of the entrance area is 0.075 m^2, the area of the output area is 0.0153386 m2, height is 1.1 m, the area of waste particles is 0.007 m2.

2. The grid is selected according to a multifaceted scheme to provide a balanced solution to complex.

Surface meshes are a discrete representation of the geometry of the individual areas that will be used to generate volumetric meshes. It consists of faces (triangles) and vertices and connects all surfaces of the geometry. A total of 70898 cells and 397585 surfaces are used to implement the calculation.

In the three-dimensional motion simulation under consideration, it was assumed that the flow is stationary, i.e. does not depend on time, the density of water and particles of contaminated liquid are constant, and the flow of water is incompressible.

In the simulation of turbulence, the Navier-Stokes differential equation is used, where the averaging process can be considered as temporary for stationary states and averaging the set for repeated transition situations and the continuity equation. The boundary and initial conditions were selected on the basis of experimental data.

At the inlet of the hydrocyclone, the velocity of the supplied suspension was 0.38 m / s, and the initial pressure was 1100 kPa. The results of pressure on a symmetric section of a hydrocyclone show that the outlet pressure drops to 550 kPa. This is in the permissible errors coincide with the subsequent experimental data.

The ratio of the amount of water and particles of contaminated liquid in the calculation is in the order of 3: 1. Figure 3 shows the proportion of particles and their distribution in the hydrocyclone by weight. It turned out that the maximum fraction of particles is at the entrance (0.35) and approximately 0.05 at the exit.

Due to the fact that during the operation of a hydrocyclone, centrifugal forces exert a significant effect on mechanical particles and the difference in the densities of the components considered the position of the particles under various possible modes of operation. The established features are to a certain extent characterized by the model solution shown in figure 4.

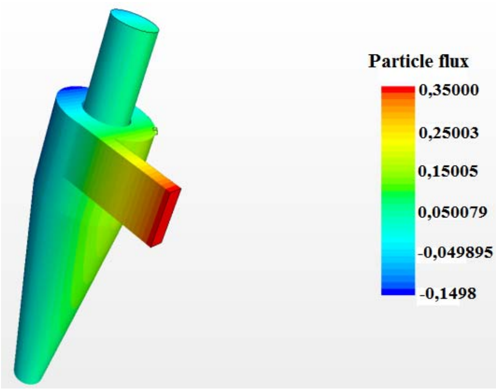

Figure 3 – Mass fraction of mechanical particles

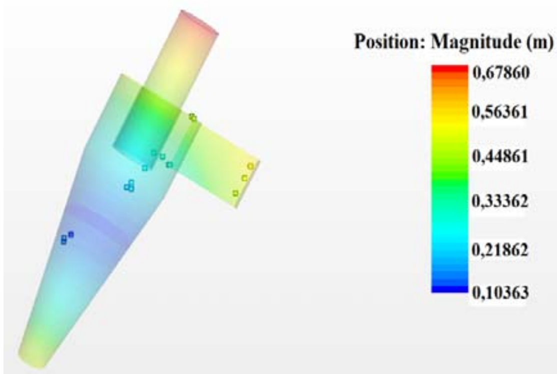

Figure 4 – Location of sand in a hydrocyclone

In the future, it is planned to consider models for establishing the optimal operating modes of a hydrocyclone with changes in the properties and states of the studied phases of the medium.

The main technological parameters and the rational mode of operation of the proposed water treatment unit were established according to the results of tests on a specially constructed laboratory installation (figure 5).

On the first table the main part of the research facility was located, based on the centrifugal pump 1.5KM with step-by-step power control, parameters of the pressure hydrocyclone and a hydroturbine.

On the second table was installed a personal computer with a program for monitoring the work of the bench installation and a communication cabinet with controls and measurements, as well as a module for connecting sensors to a personal computer.

A hydrocyclone with a cylindrical part diameter of 170 mm and a height of 480 mm was adopted for testing. The diameters of the inlet and outlet nozzles are the same and are 60 mm, and the diameters of the sand hole are 40 mm.

Figure 5 – Laboratory stand (a) and a hydraulic turbine with a generator (c)

Results of the investigation. As the data obtained under laboratory conditions show, when the pump is operating with a capacity of up to 250 l / min, the dependence of the water supply Q on the pressure at the inlet to the hydrocyclone P1 occurs in the same way as in ordinary centrifugal pumps. The pressure loss is 10-20%. In this case, due to the supply of purified water after the hydrocyclone to the water intake tank directly, the indicators of the electronic sensor at the inlet of the hydraulic turbine P2 and at the outlet P3 are insignificant

In order to establish the energy characteristics of the installation, the "hydroturbine-generator" unit was specially studied. In this case, three modes were considered: the operation of the unit at maximum load (P1), at average load (P2), and at minimum load (P3).

The results obtained for establishing the generated power are shown in figure 6. They show that the value of the generated power (energy) directly depends on the pressure on the line and on the rotational speed of the generator shaft.

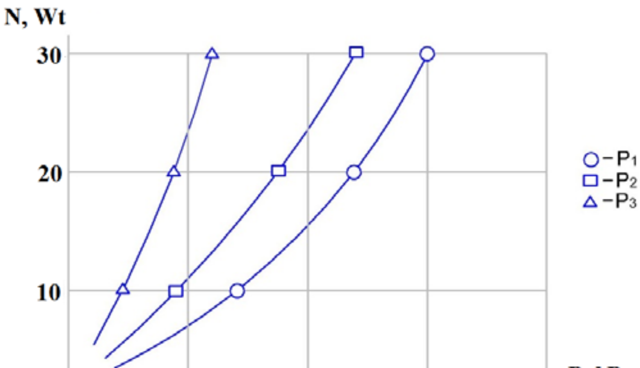

Figure 6 – Results of testing the unit "hydro turbine - generator"

As a result of the production test, it was found that when the pressure at the inlet of the prototype hydrocyclone changes within Pin = 25 - 45 kPa, there is an increase in the flow rate of liquid through the drain pipe Q in from 5.78 l / s to 57.5 l / s, and through sand hole Qp.o. - up to 4.42 l / s.

As can be seen from the graphical dependences Qout = f (Pout) and Qin = f (Pin) (figure 7), the maximum flow rate of the hydrocyclone through the drain (57.5 l / s) is provided at an inlet pressure of 45 kPa, when the valve on the pressure line is open to the full cross section. The pressure loss in the hydrocyclone chamber at the same time is 2,2 ... 3,5 kPa.

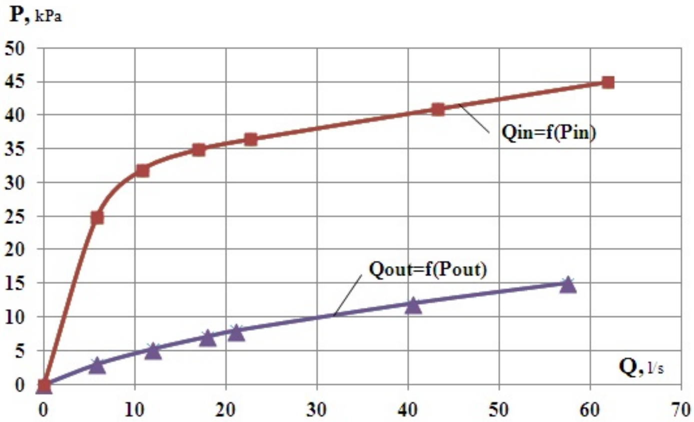

Figure 7 – Graphic dependences Qout = f (Pout) and Qin = f (Pin)

During the tests, by changing the diameter dp from 10 to 25 mm, the concentration of the ground mass was reached with a ground weight consumption of 0.73 ... 0.77 kg / s and a density of up to 1.843 t / m3) significantly increases the density of the condensed mass, however, this leads to clogging of the discharge opening.

In the established mode, the clarified water density was equal to 1.009 ... 1.05 t / m^3, and the degree of purification - 91 ... 97%. The minimum particle size was 0.05 mm, and the maximum particle size was 3.75 mm.

It has been established that the required type of hydrocyclone in the design should be adopted on the basis of a technical and economic comparison of the construction and operational indicators of the water treatment unit, taking into account the presence of a sufficient hydraulic slope of the water supply path and free water flows necessary for separating a two-phase liquid.

For the calculation and design of hydrocyclone sanding units, the same parameters for water and pollution should be specified as for sedimentation tanks. The hydraulic size of particles, which must be isolated to provide the required cleaning effect, is determined at the required height of water layer. The main design value of the hydrocyclones is capacity for purified water and degree of purification. Water productivity Qout *(Qhc)* can be calculated by the formula taking into account the diameter of hydrocyclone *Dhc:*

$$Q_{hc} = 0{,}785 q_{hc} D_{hc}^2 \quad (1)$$

Based on the total amount of water Qw supplied, the number of hydrocyclone working units is determined: N = Qw / Qhc. After the designation of the devise diameter and determination of their quantity, basic parameters of the hydrocyclone were established.

The angle of inclination of the generatrix conical part of the hydrocyclones in each specific case is set depending on the properties of the precipitate being precipitated. The main components and parts of hydrocyclones can be made of steel and plastic materials.

In view of the fact that hydrocyclones of considerable diameter (700-1000 mm) are analogous to ours, they are installed in those nodes of the technological scheme in which it is necessary to process volumes of contaminated water at the size of the boundary grain separation 0.4-0.5 mm, within these limits. With low productivity and the need to separate sand of small size (0.2-0.4 mm), as in the case of cooling water in the node of technical water supply of hydroelectric power stations, hydrocyclones with diameters within 350-500 mm are recommended.

Conclusions. Tested in production conditions, prototypes of a hydrocyclone sand trapping unit with a diameter of 700 mm showed the degree of water purification from mechanical impurities up to 91-97%. The installed capacity of one hydropower plant in use is 3-10 MW. Annual power generation reaches 4.0 - 5.0 million kWh.

Replacing the bulky reinforced concrete sedimentation tank of the existing hydroelectric power plants with hydrocyclone sand traps of a simplified design reduces the costs of building a water treatment unit from 30% (existing) to 7%.

The economic effect from the use of the developed technology of water supply for the hydroelectric unit of a small hydroelectric power station is achieved by simplifying the sand collection unit and thereby reducing capital investments for construction and operating costs.

Achieving a stable operating mode of the hydroelectric unit and its accompanying main units of the hydroelectric power station without special stops allows reducing losses in electricity supply to 15-20%.

The originality and effectiveness of the solution was awarded a certificate and medal of the World Intellectual Property Organization (WIPO). The basic version of the proposed hydroelectric power station was demonstrated at EXPO-2017 (Astana, Kazakhstan) and received expert approval.

The considered option of the hydroelectric power plant was additionally studied within the framework of the target program "Creation of the basis for the serial production of renewable energy sources in Kazakhstan of the world level" (BR05236263, National Academy of Sciences, Kazakhstan).

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МИНИ ГЭС-ке АРНАЛҒАН ГИДРОЦИКЛОНДЫҚ ҚҰМТҰТҚЫШ ЖАСАУ ЖӘНЕ СЫНАҚТАН ӨТКІЗУ

Аннотация. Жобаның мақсаты – шағын (мини) гидроэлектрстанция жұмысын жетілдіру үшін гидроциклонды құмтұтқыш жасау және пайдалану. Жасалған технологияның бұрынғы ұқсас түрінен айырмашылығы – суды тазартуға арналған көлемді тұндырғыш тиімді гидроциклон қондырғысымен ауыстырылғандығында. Соның нәтижесінде су электр станциясын жобалауды оңайлатуға, пайдаланылған су құрамынан құм алу дәрежесінің жоғарылауына қол жеткізеді.

Зерттеу әдістері. Есептеу үшін мынадай мәліметтер алынды: гидроциклон арқылы өтетін су шығыны және гидроциклон кірісі мен шығысындағы қысымның төмендеуі. Үдерісті компьютерлік модельдеу SolidWorks бағдарламалық жасақтама (ағынды модельдеу) арқылы жүзеге асырылды. Негізгі технологиялық параметрлер мен рационалды жұмыс режимі тәжірибелік үлгілерді зертханалық және өндірістік жағдайда сынау арқылы белгіленді.

Зерттеу нәтижелері. Белгіленген режимде тазартылған су тығыздығы 1,009 ... 1,050 т / м^3, ал тазарту дәрежесі 91 ... 97% құрайды. Ірі темірбетонды тұндырғышты жеңілдетілген гидроциклонды құмтұтқышқа ауыстыру, су тазарту қондырғысын салуға кететін шығынды 30%-дан (қолданыстағы) 7%-ға дейін төмендетеді. Бұл таулы аймақтардағы шағын су электр станцияларының даму жағдайын арттыруға мүмкіндік береді.

Түйін сөздер: мини ГЭС, жасау, гидроциклондық құмтұтқыш, үдерісті модельдеу, тәжірибелік стенд, сынақтар.

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РАЗРАБОТКА И ИСПЫТАНИЕ ГИДРОЦИКЛОННОЙ ПЕСКОЛОВКИ ДЛЯ МИНИ ГЭС

Аннотация. Целью проекта является разработка и использование гидроциклонной песколовки для улучшения работы мини-гидроэлектростанции. В отличие от существующей конструкции гидроэлектростанции аналогичного типа, громоздкий отстойник для очистки воды был заменен эффективным гидроциклонным устройством. За счет этого достигается упрощение конструкции ГЭС, увеличение степени сбора песка из состава используемой воды.

Методы исследования. Исходными данными для расчета были взяты: расход воды, проходящей через гидроциклон, и перепад давления на входе и выходе гидроциклона. Компьютерное моделирование процесса проводилось с использованием программного обеспечения SolidWorks (flow simulation). Основные технологические параметры и рациональный режим работы были установлены путем испытаний экспериментальных образцов как в лабораторных, так и в производственных условиях.

Результаты исследований. В установленном режиме плотность осветленной воды равна 1,009 ... 1,050 т/м^3, а степень очистки – 91 ... 97%. Замена громоздкого железобетонного отстойника гидроциклонными песколовками упрощенной конструкции снижает стоимость строительства установки очистки воды с 30% (существующей) до 7%. Это дает возможность расширить объемы освоения малых гидроэлектростанций, особенно в горных условиях.

Ключевые слова: мини ГЭС, разработка, гидроциклонная песколовка, моделирование процесса, экспериментальный стенд, испытания.

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