Improvement of the Work of a Small Derivative Hydro-Electrostation by Water Treatment by Hydrocyclones

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Abstract: The relevance of the study lies in the fact that in the common derivation schemes of hydroelectric power plants, protection against bottom and bottom sediments is carried out in water inlets, and water is cleaned from dangerous fractions of sediments in sedimentation tanks. The costs for the construction of a sump are very significant and sometimes make up 20-35 % of the investments in the construction of hydroelectric power stations. In our opinion, it is possible to reduce these costs by using modern types of hydrocyclones instead of sumps and filters used to purify water for cooling generators. The purpose of the work is to increase the efficiency of small hydropower plants by improving the site of water treatment. The research method is the use of guidelines for the preparation of technical documentation for energy production and technological complexes of hydroelectric power stations and thermal power plants and the testing of a water treatment unit and a technical water supply system. The results obtained: a feature of a new technical solution to improve a small hydropower plant was established. Unlike the existing ones, it has a complex clarifier for water purification replaced by an effective hydrocyclone. The hydrocyclone is also installed on the cooling unit of the hydrogenerator. Due to this, a simplification of the design of hydroelectric power stations, increasing the degree of water purification is achieved. The results of calculating the design parameters of hydrocyclone assemblies and testing them in laboratory and production conditions are presented. It has been established that replacing the bulky reinforced concrete sump of existing hydropower plants with simplified design hydrocyclone sand traps reduces the cost of building a water treatment unit from 30% (existing) to 7%. This allows you to expand the scope of development of a small hydroelectric power station, especially in mountain conditions.

1 INTRODUCTION

It is well known that hydropower is the most widespread in practice and technologically advanced industry in renewable energy sources [1-5].

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.

The main stimulating factors for the construction of small hydropower plants are [6]:

- constant renewability of water resources;
- minimal environmental impact;
- low cost of electricity compared with thermal power plants;
- significant savings in mineral fuels;
- improvement of household conditions and labor of people;
- low capital intensity, short investment cycle.

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 [10-12]. 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 [15].

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 [6, 20].

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 [6]. Therefore, the feasibility of building a hydropower plant with a settling tank should be justified by special technical and economic calculations. For this, the cost of installing a settling tank is usually compared with the cost of cleaning the structures from sediment and repairing turbines that will be required if the construction of the settling tank is abandoned. periodic removal of sediment deposited in the sump.

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 [21].

2 DESCRIPTION OF THE DEVELOPMENT AND METHODOLOGY OF THE INVESTIGATION

The small derivational power station developed by us includes a hydrocyclone water treatment unit 1, a building of hydroelectric power station 2, a hydroturbine 3, a generator 4, a hydrocyclone 5 for a cooling unit of the generator and a suction tube 6 (Figure 1) [19].

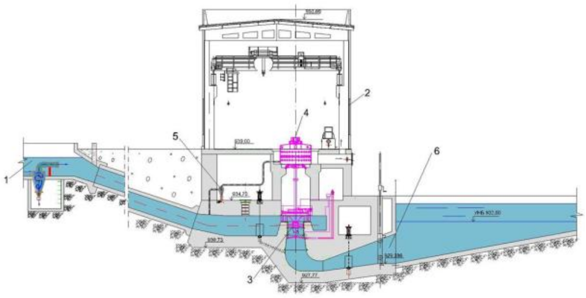

Figure 1: Design diagram of the small derivational power plant with hydrocyclone water treatment unit.

In Figure 1 shows 1-hydrocyclone water treatment unit; 2-building of hydroelectric power station; 3-hydroturbine; 4-generator; 5-hydrocyclone for the cooling unit; 6-suction pipe.

The water purification unit consists of hydrocyclones with a receiving chamber and a drainage pipe, a threshold, a manhole and a sand pipe. The threshold set inside the derivation channel is provided in order to ensure the full flow of water with mechanical impurities into the receiving chamber of the hydrocyclone. Therefore, the threshold height must be at least the height of the cylindrical part of the hydrocyclone.

To fully ensure the required water flow, a parallel arrangement of hydrocyclones is provided for (Figure 2).

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.

Figure 2: Parallel arrangement of hydrocyclones in the hydroelectric diversion channel.

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.

The result of the study made a prediction of the degree of water purification, depending on the physical properties of the fluid, the flow rate at the inlet and the geometric parameters of the hydrocyclone.

From the experiments performed in the laboratory were initially known: inlet pressure Рвх = 1100 kPa; speed v = 0,3844 m/s; fluid flow Q = 173 l/min = 2,88 kg/s;

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

- Dimensions of the hydrocyclone: the area of the entrance area is 0,075 m^2, the area of the output area is 0,0153386 m^2, height is 1,1 m, the area of waste particles is 0,007 m^2.
- The grid is selected according to a multifaceted scheme to provide a balanced solution to complex. And also the model of a prism-grid layers is used to generate orthogonal prismatic grids with a wall border. This layer of cells is necessary to improve the accuracy of the solution of the flow movement. 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.

Due to the fact that the fluid movement is two-phase, we can use the Lagrange multiphase model, i.e. phase 1 - water, phase 2 - particles of mechanical impurities.

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.

The Reynolds (1) are written in the form:

$$\rho\frac{\partial \bar{u}_j \bar{u}_i}{\partial x_j} = \rho \bar{f}_i + \frac{\partial}{\partial x_j}\left[-\bar{p}\delta_{ij} + \mu\left(\frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i}\right)(1) \quad \overline{u'_i u'_j}\right].$$

Then, the continuity (2):

$$\frac{\partial \rho}{\partial t} + \mathrm{div}\, \rho \mathbf{v} = \frac{\partial \rho}{\partial t} + \rho\, \mathrm{div}\ \mathbf{v} + \mathbf{v}\, \mathrm{grad}\, \rho = (2)$$

At the inlet of the hydrocyclone, the velocity of the supplied suspension was 0,38 m/s, and the initial pressure was 1100 kPa. At the outlet, the state of purified water met the expected requirements for the degree of purification.

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 change in pressure in a hydrocyclone is characterized by the model shown in Figure 3.

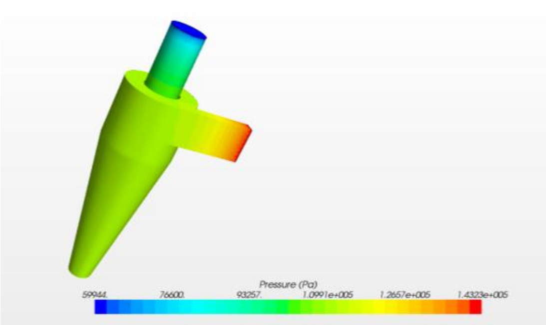

Figure 3: Pressure change in a hydrocyclone.

The ratio of the amount of water and particles of contaminated liquid in the calculation is in the order of 3:1. In Figure 4 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 5.

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 6). [21].

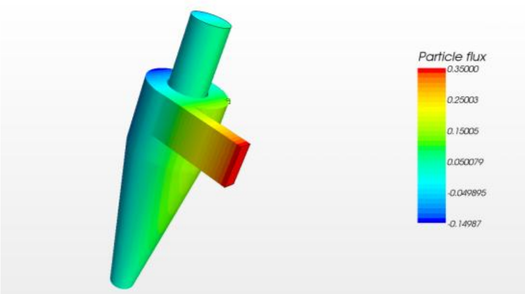

Figure4: Mass fraction of mechanical particles.

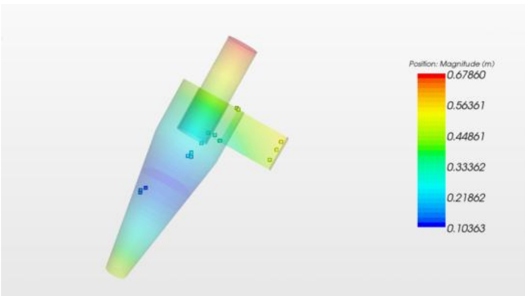

Figure 5: The location of the dirt particles in the hydrocyclone.

On the first table the main part of the research facility was located, based on the centrifugal pump 1,5 KM with step-by-step power control, parameters of the pressure hydrocyclone and a hydroturbine.

To change the operating mode, we used valves, electronic pressure sensors installed at the assembled units of the hydraulic unit, and also an electronic flowmeter. Under the table there was a container for circulating water supply, into which liquid is supplied from the suction pipe of the small hydroelectric power station.

Figure 6: Laboratory installation for studying the parameters of hydroelectric power stations with a hydrocyclone.

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.

On the basis of the above theoretical assumptions and the calculation procedure, the following dimensions were calculated for the manufacture of experimental industrial samples (Table 1).

Table 1: The main dimensions of the projected hydrocyclones.

Options	GC-700 (node 1)	GC-500 (node 2)
Diameters, mm:		
Cylindrical part	700	500
The inlet nozzle	90*330*65	70*200
Drain connection	200	100
Sand hole	50	32
Angle, taper, degree	30-35	20
Height of cylindrical part	380	250
Taper height	1185	750
Diameter of the air column	52	45
Minimum particle size	0,05	0,05
Maximum particle size	3,75	2,75

3 RESULTS OF THE INVESTIGATION

As a result of the test, it was found that when the pressure at the inlet of industrial sample of the hydrocyclone changes within 0,025 ... 0,045 MPa, an increase in the flow rate of liquid through the discharge pipe from 5,78 l/s to 57,5 l/s is observed, and through the sand hole - up to 4,42 l/s (Table 2).

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 22 ... 35 kPa.

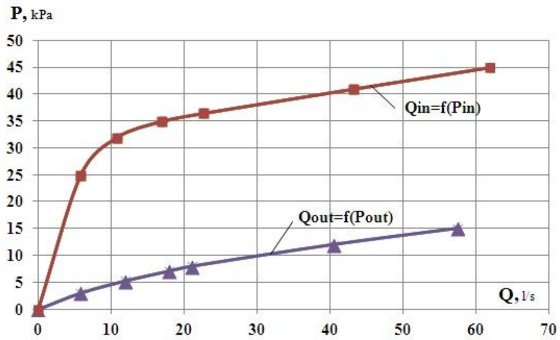

Figure 7: Graphic dependences Qout = f (Pout) and Qin = f (Pin).

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/m^3) significantly increases the density of the condensed mass, however, this leads to clogging of the discharge opening (Table 3).

In the established mode, the clarified water density was equal to 1,009 ... 1,05 t / m3, and the degree of purification - 91 ... 97%. The minimum particle size was 0,05 mm, and the maximum particle size was 3,75 mm.

The choice of the location of the designed hydrocyclone gritters, as well as the replaced septic tanks, is provided within the head node or on the main (diversion) channel taking into account the geological and topographical conditions, the approach of water to the water treatment unit.

Table 2: Discharge characteristic of a hydrocyclone at pressure mode.

Pressure, kPa				Consumption, l/s	
At the entrance of a hydrocyclone, Pin	On the sink of a hydrocyclone, Pout	On the sand hole of a hydrocyclone, Ppo.	At the entrance of a hydrocyclone, Qin	Through the discharge of a hydrocyclone, Qout	Through the sand hole of a hydrocyclone, Qpo.
25	3,0	2,0	5,83	5,78	0,05
32	5,3	4,0	12,26	12,0	0,26
35	7,1	5,0	18,64	18	0,64
36	8,0	6,0	22,72	21,1	1,62
41	12,0	8,0	43,27	40,5	2,77
45	15,0	10,0	61,92	57,5	4,42

The required type of hydrocyclone is made on the basis of a technical and economic comparison of the construction and operational parameters of the water treatment unit, taking into account the presence of a sufficient hydraulic slope of the water supply path and the free flow of water necessary to separate the two-phase liquid.

Table 3: These tests for determining the degree of water purification with a mechanical impurity in a hydrocyclone.

Pressure at the inlet of a hydrocyclone, kPa	Density of liquid and pulp, t/m3		Degree of cleaning, %
	clarified water	condensed water	
20	1,020	1,520	91
30	1,009	1,680	92
40	1,025	1,720	94
50	1,031	1,745	96
60	1,035	1,780	97
70	1,040	1,800	97
80	1,034	1,843	96
100	1,050	1,840	94

In view of the fact that the designed sand trap will be installed on the bottom of the diversion channel, its main parameters should ensure optimal operation of the channel and hydroelectric turbine of the hydroelectric station.

The water turbine system is selected at the maximum head taking into account the set operating conditions and the range of pressure change at the hydroelectric power station.

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 *(Qhc)* can be calculated by (3) taking into account the diameter of hydrocyclone *Dhc:*

$$Q_{hc} = 0{,}785 q_{hc} D_{hc}^2 \qquad (3)$$

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.

The hydropower plant under consideration is designed in accordance with the target program “Creation of a basis for serial production of renewable energy sources in Kazakhstan of world level” (BR05236263, National Academy of Sciences, Kazakhstan).

CONCLUSIONS

It has been established that the hydrocyclone method for trapping mechanical impurities has a number of significant advantages over other methods of water purification, in particular from a settler:

- simplicity of hydrocyclone design, adjustment, operation, installation
- and high service life of the water supply unit;
- high degree of purification from abrasive mechanical particles;
- slight loss of liquid through the sand nozzle - up to 2-3 %;
- lack of an autonomous pump and drive, because works due to the drop of the derivation channel or pipe.

If it is needed they can be replaced with new ones or restored during the operation of the small hydroelectric power station.

Approved in production conditions, prototypes of the hydrocyclone water supply unit with a diameter of 700 mm showed the degree of water purification from mechanical impurities to 96-98 %. The installed capacity of one used hydroelectric power station is 3-10MW. Annual power generation reaches 4,0 – 5,0 million KW.

Replacing the bulky reinforced concrete clarifier of existing hydroelectric power stations with hydrocyclone sand traps of simplified construction reduces the cost of building a water treatment unit from 30 % (existing) to 7 %. , which were calculated by comparative assessment of the sump and the proposed hydrocyclone unit. This allows you to expand the volume of development of small hydropower plants, especially in mountain conditions.

The main consumers of development are energy services, interested in non-traditional energy sources and private organizations.

The economic effect of using the proposed technology of water supply of a hydroelectric unit of a small hydroelectric power station is achieved through the replacement of an expensive sedimentation tank and complex filters for water purification on hydrocyclones. Achievements of a stable operating mode of the hydrounit and associated main hydroelectric power station nodes without special stops contribute to reducing the loss in power supply to 15-20 %.

The technical novelty of the development is confirmed by patent of the Republic of Kazakhstan No. 25130,2014. Originality and effectiveness of the solution is marked by a certificate and a medal of the World Intellectual Property Organization (WIPO). The current model of the proposed hydroelectric power station was demonstrated at

EXPO-2017 (Astana, Kazakhstan) and was approved by specialists.

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