Modeling the classification ability of filtering hydrocyclone

M I Lamskova\(^1,2\), M I Filimonov\(^1,2\), A E Novikov\(^1,2\) and C V Borodychev\(^3\)

\(^1\)Volgograd State Technical University, 28, Lenina Avenue, Volgograd, 400005, Russia
\(^2\)All-Russian Research Institute of Irrigated Agriculture, 9, Timirjaseva St., Volgograd 400002, Russia
\(^3\)Volgograd Branch of the All-Russian Research Institute for Hydraulic Engineering and Land Reclamation, 9 Timiryazev St. 400002, Volgograd, Russia

*E-mail: lamskov@yandex.ru

Abstract. The construction of a hydrocyclone with the filtering side surface drain pipe has been developed, which allows increasing the water purification rates from mechanical impurities, including by capturing the smallest suspensions. As a result of experimental research of the effect of the flow characteristics and size of the sand pipe on the classification ability of the apparatus, the technological and construction parameters of the PH-100 hydrocyclone with various versions of the drain pipe, providing maximum efficiency of water purification from mechanical impurities, have been established. Graphoanalytic solution of the obtained regression equations has allowed us to establish that a hydrocyclone with a solid side surface drain pipe provides the maximum degree of water purification from mechanical impurities at the level of 85.4\% at a flow rate of 6.5 m\(^3\)/h and a diameter of 12 mm sand pipe. Replacing the standard construction drain pipe with a filtering side surface drain pipe increases the integral degree of water purification from mechanical impurities to 96.4\% with the same flow parameters and the diameter of the sand pipe.

1. Introduction
Special attention is paid to the issues of water treatment in reclamation systems, since the operational reliability of irrigation equipment and the quality of irrigation depend on the effective operation of this node. The standard water treatment unit includes primary purification with catchers and granular loading filters when taking water from a water source and at the points of transition from main pipelines to distribution pipelines, and fine purification on disk or mesh filters on local distributors. This multi-stage water treatment system is characterized by the complexity of its maintenance, a high probability of failure due to the sequence of the process and the dependence of the final stages water filtration of the preceding ones.

Usage cylindrical-conical pressure hydrocyclones (PH), which have proven themselves in circulating water distribution systems of national and foreign industry, is promising for water treatment technology. The apparatus are characterized by high productivity and efficiency of water purification from mechanical impurities at a relatively small size and cost, low resource consumption for operation [1-3]. One of the main problems when using this type apparatus is the entrainment of the smallest suspensions with a purified liquid flow, but it also finds a solution in research aimed at optimizing the construction of hydrocyclones, mainly to solve the compromise problem of increasing the classification ability maintaining their water consumption and cost indicators [4-8].

One of the ways to solve the problem of increasing parameters of water purification from
mechanical impurities, including by capturing the smallest suspensions, is using cascades of various sizes hydrocyclones. The implementation of a sequential centrifugal separation process provides for a finer classification of mechanical fractions at each subsequent stage. However, the multi-stage and sequence of the hydrocycloning process on the one hand increases the size and weight indicators of the water treatment unit, and on the other hand does not exclude interruptions in its operation when the process is disrupted at separate stages [9, 10]

A more promising solution to this problem may be the use of filtering hydrocyclones. In [11], we consider the construction of the apparatus with the perforated conical part. An additional liquid flow occurs in this version of the hydrocyclone, which is formed by water filtration through the cone. However, this not only complicates the construction, but also reduces its manufacturability, since there is a problem of placing a porous cone in a sealed casing for collecting and further removing the filtrate (purified water).

Thus, taking into account the analysis of literature sources, the parameters affecting productivity indicators of the hydrocyclone can be divided into two groups - constructive and technological. The first group includes the geometrical dimensions of the apparatus, namely the diameter and height of cylindrical and conical parts, diameter and immersion depth of the drain pipe, the diameter of the sand pipe, the cone angle and the shape, size and angle of the input pipe. Technological parameters of the apparatus are its productivity (flow characteristics), pressure before the input pipe (pressure characteristics), granulometric composition, density and concentration of mechanical impurities in water [12].

The productivity of the hydrocyclone is one of the most important technological factors, since it determines the speed of the radial and rotational liquid flow motion in the corpus of apparatus, and, accordingly, the amount of centrifugal force acting on the particle, as well as quantity of liquid discharged through the pipes. So, for example, at a low speed of the liquid flow, the water pressure may be insufficient to overcome the hydraulic resistance of the apparatus and part of it will be removed through the sand pipe with the sludge, as a result, the classifying ability and purified water productivity of the hydrocyclone will be reduced.

The dimensions of the drain and sand pipes also determine the classifying ability of the hydrocyclone, since deviations from the optimal value of the ratio of their diameters leads to a redistribution of liquid flows between the discharge pipes and changes in the quantitative and qualitative composition of the sludge. Thus, varying the productivity and parameters of the drain and sand pipes allows to control the process of hydrocycloning.

The purpose of the research has been to develop the construction of a filter hydrocyclone and assess the impact of the flow characteristics and the sand pipe size on the classifying ability of the apparatus in the process of water purification from mechanical impurities.

2. Materials and methods
To increase the classifying ability of the hydrocyclone, including by capturing the smallest suspensions, it has been developed a construction of apparatus with the filtering side surface drain pipe [13] (figure 1). The process is implemented as follows. Water flows through the input pipe into the cylindrical part of the corpus tangentially, the liquid flow swirls and heavy fractions of mechanical impurities, hitting the wall, descend along the conical part of the corpus and are removed through the sand pipe. Then the water passes through the filtering side surface of the drain pipe, it is cleared of small fractions of mechanical impurities and diverted, for example, to the local irrigation system.

Experimental researches of the classifying ability of the filtering hydrocyclone in the water purification from mechanical impurities have been carried out on a laboratory installation including PH-100 hydrocyclone 1, containers for source 2 and purified water 3, container for slurry suspension 4, a pump 5, control and measuring devices 6, a transport system 7 and a shut-off valve 8 (figure 2). The drain pipe is removable in two versions - with a solid side wall (standard design) and with a filtering side surface with a mesh cell diameter of 300 microns (experimental design).
The experiments aimed to evaluate the classification ability of PH-100 hydrocyclone with different drain pipe designs in the process of water purification from mechanical impurities that have been carried out with varying flow rates in the range from 6.7 to 7.0 m³/h and the diameter of the sand pipe in the range from 8 to 16 mm by installing spacers of the required size.

Sand with a density of 1300-1500 kg/m³ has been added to the water subject to centrifugal separation in the range of dispersion from 150 to 600 microns and a concentration of 5-25%, which is due to similar mechanical impurities in water when it is taken from open water sources and transported through the irrigation network.

The efficiency of water purification from mechanical impurities has been estimated by the integral indicator \( \eta \), which characterizes the proportion of captured particles of all fractions relative to their initial concentration.

The results of the experiment have been evaluated using statistical Fischer criteria \( F \), Student criteria \( t \), and program Statgraphics 18.

3. Results and Discussion

The analysis of experimental data obtained from the results of the experiment on the dependence of the integral degree of water purification from mechanical impurities in a PH-100 hydrocyclone on the studied parameters revealed the following regression patterns:

- for a hydrocyclone with a solid side wall of the drain pipe:

  \[
  \eta = -207 + 166X_1 - 34.96X_2 - 26.34X_1^2 + 2.52X_2^2 + 1.38X_1^3 - 0.08X_2^3 + 3.73X_1X_2 - 0.3X_1^2X_2 - 0.001X_1X_2^2, 
  \]  

(1)

- for a hydrocyclone with a filter side surface of the drain pipe:

  \[
  \eta = 46.21 + 38.37X_1 - 16.61X_2 - 5.29X_1^2 + 1.59X_2^2 + 0.21X_1^3 - 0.05X_2^3 + 0.5X_1X_2 + 0.04X_1^2X_2 - 0.024X_1X_2^2, 
  \]  

(2)

gде \( X_1 \) - water consumption, m³ / hour;  
\( X_2 \) - diameter of the sand pipe, mm.

Graphoanalytic solution of regression equations (1) and (2) is presented as a response surface to figure 3. They reflect the dependence of the integral degree of water purification from mechanical impurities when varying the parameters of water flow and the diameter of the sand pipe for a hydrocyclone with a solid side and a filtering side surface of the drain pipe.
Figure 3. The dependence of the integral degree of purification on the parameters of water flow and the diameter of the sand pipe for a hydrocyclone with a solid side (a) and a filtering side (b) surface of the drain pipe.

The evaluation of regression equations (1) and (2) by comparing the critical (2.39) and the estimated Fischer criteria (1.1 and 1.15) it is established that mathematical expressions adequately describe the dependence of the integrated degree of purification from the parameters of water flow and diameter of the sand pipe with model and experimental drain pipe design. The coefficients of equations (1) and (2) are significant, which is confirmed by the excess of the calculated values of the Student criteria (2.07-1526 and 2.08-326) over their critical value (2.04). It should be noted that the regression equations can be valid for other suspensions, but only if they are similar in composition and properties to the studied one.

4. Conclusion
As a result of experimental research, technological and constructive parameters of the PH-100 hydrocyclone operation have been established, namely, the flow characteristics of the apparatus and the diameter of the sand pipe, which ensure maximum efficiency of water purification from mechanical impurities.

Graphoanalytic solution of the obtained regression equations has allowed us to establish that a hydrocyclone with a solid side surface drain pipe provides the maximum degree of water purification from mechanical impurities at the level of 85.4% at a flow rate of 6.5 m³/h and a diameter of 12 mm sand pipe. Replacing the standard construction drain pipe with a filtering side surface drain pipe increases the integral degree of water purification from mechanical impurities to 96.4% with the same flow parameters and the diameter of the sand pipe.

5. Acknowledgments
The reported study was funded by the support of the grant of the President of the Russian Federation no MK-2289.2020.8.

References
[1] Golovanchikov A B, Novikov A E, Lamskova M I and Filimonov M I 2018 Modeling the Process of Separation of Non-Homogeneous Liquid Disperse Systems in a Hydrocyclone Accounting for Similarity Criteria Chemical and Petroleum Engineering 54 118
[2] Yablonskii V O 2019 Influence of Operating Parameters of a Cylindrical Hydrocyclone on Separation Factor of Nonlinearly Viscoplastic Suspensions Chemical and Petroleum Engineering 55 265
[3] Yablonskii V O 2020 The Influence of Plastic Properties of a Suspension on the Separation Index of a Cylindrical-Conical Hydrocyclone Chemical and Petroleum Engineering 55 800
[4] Jiang L Y, Liu P K, Zhang Y K, Yang X H, Wang H and Gui X H 2019 Design boundary layer
.p finder on the performance of cyclone separator Powder Technology 313 135
[5] Ghodrat M, Kuang S B, Yu A B, Vince A, Barnett G D and Barnett P J 2014 Numerical analysis of hydrocyclones with different conical section designs Minerals Engineering 62 74 Hwang K J, Hwang Y W, Yoshida H and Shigemori K 2012 Improvement of particle separation efficiency by installing conical top-plate in hydrocyclone Powder Technology 232 41
[6] Silva N K, Silva D O, Vieira L G and Barrozo M A 2015 Effects of underflow diameter and vortex finder length on the performance of a newly designed filtering hydrocyclone Powder Technology 286 305
[7] Lanyue J, Peikun L, Yuekan Z, Xinghua Y and Hui W 2019 The Effect of Inlet Velocity on the Separation Performance of a Two-Stage Hydrocyclone Minerals 9 209
[8] Lamskova M I, Filimonov M I, Novikov A E, Samofalova L V and Pavlova S V 2019 Modeling of the Separation for System the Liquid - Solid in the Battery of Hydrocyclones J. of Physics: Conference Series 1278
[9] Vieira L G, Damasceno J J and Barrozo M A 2010 Improvement of hydrocyclone separation performance by incorporating a conical filtering wall. Chem. Eng. Process. 49 460
[10] Svarovsky L and Thew M T 1992 Hydrocyclones: Analysis and Applications (Dordrecht: Kluwer Academic Publishers) 440 p
[11] Golovanchikov A B, Novikov A E, Lamskova M I and Filimonov M I 2017 Modeling of hydrodynamic processes in the centrifugal field of hydrocyclones (Volgograd: VSTU) 200 p
[12] Bauman A V 2018 Hydrocyclones. Theory and practice (Novosibirsk: gormashexport) 56 p