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Regulation of hydrocyclone parameters to improve the quality of water purification on drip irrigation systems

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ABSTRACT

The reliability of drip irrigation systems depends on the quality of water purification of the water sources used. The degree of its purification is a particularly important factor affecting the performance of all components of irrigation systems, including droppers. The purpose of the study was to assess the applicability of a hydrocyclone with adjustable parameters to improve the quality of water purification in drip irrigation systems. The research was carried out using the method of comparative tests of various configurations of sections of the inlet pipe of the hydrocyclone, considering changes in their angle of inclination along the vertical plane and changes in the depth of immersion of the drain pipe. By changing the configuration of the inlet pipe of the hydrocyclone, the angle of deviation along the vertical (θ^o) and horizontal (φ^o) planes, as well as the depth of immersion of the drain pipe (a_c), the effect on the distribution of the flow rates between the discharge holes required for the quality of cleaning has been established. It has been found that the greatest clarification of water is provided with the semicircular shape of the inlet pipe, with the inclination of the inlet pipe along the vertical plane $\theta^o = 2^0 \ldots 4^0$, with the immersion of the drain pipe to the interface plane of the cylindrical and conical parts of the hydrocyclone.

Keywords: Drip irrigation system, Hydrocyclone, Cleaning quality.
Article type: Research Article.

INTRODUCTION

In agricultural irrigation, currently, the most relevant and economical irrigation type for crops is drip irrigation, where water is supplied in small doses directly under the root of the plant. The main advantages of such irrigation can be called water conservation, optimal provision of plants with nutrients, and the exclusion of weed germination since the soil in the space between rows remains dry (Kalashnikov *et al.* 2017, 2022). Water supply to drip irrigation systems is carried out from surface or underground sources. One can use storage tanks in the form of reservoirs, tanks, cisterns, and other storage containers (Ongayev *et al.* 2022). Regulation of irrigation water supply to the drip irrigation system is carried out manually or automatically by pumps with calculated capacity and pressure. For small areas, as a water source, one can use storage tanks in the form of reservoirs, tanks, cisterns, and other containers with their installation at a height of 3-5 m above the ground surface due to the created pressure (Kalashnikov *et al.* 2020). The main factor in the design of drip irrigation systems is the assessment of the quality of the incoming irrigation water. According to the analysis of water quality, the parameters of the purification system are calculated to eliminate the possibility of clogging for droppers (emitters; Zhou *et al.* 2015). Depending on the source of water supply in the irrigation water, it is possible to have suspended sediments in the form of algae, clay, sand, and other constituent elements of various diameters and weights, the presence of which leads to clogging in droppers and failure of the drip irrigation system. For example, Fig. 1 shows a drip irrigation system with a 50-m-long hose, where droppers are installed at a distance of 30 cm from each other.

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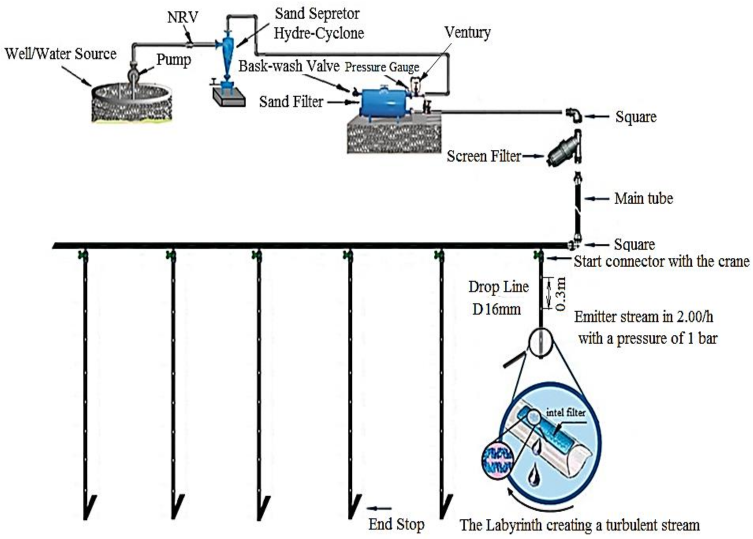


Fig. 1. Schematic diagram of the drip irrigation system

Hoses are laid along the roots of plants, so that the droppers are above the root of the cultivated plant. To eliminate the clogging in the droppers, the irrigation water should be thoroughly cleaned through filtration devices. At the beginning, expanded clay, crushed stone, and sand-and-gravel filters of the cassette type are used to clean the water from large mechanical impurities. Further, disk, mesh, and polystyrene-loaded filters are used for fine cleaning. To increase the efficiency of the filtration system, in our studies, a pressure hydrocyclone was installed in front of the sand and gravel filter to assess the possibility of capturing particles of no more than 0.5 mm in size and to establish the parameters of the hydrocyclone for the improvement of water quality on the drip irrigation system. The operation of the hydrocyclone on the drip irrigation system occurs in the following order. When water is taken from the source, it enters the inlet pipe of the hydrocyclone, where, under the action of centrifugal force, solid particles move to the inner wall of the device and, moving along a downward trajectory, are ejected through the sand pipe, while the purified water re-enters the system through the drain pipe. In the future, the sediments remaining in the liquid settle in the pores of the sand and gravel filter, and the smallest particles are captured using a mesh disk filter. Next, the water passes through the inlet filter of the dropper and its labyrinth channel (Fig. 2), where the water supply rate slows down and its flow rate is normalized with the further intake of water through the outlet to the plants. A detailed description of the drip irrigation technology on drip and sprinkler irrigation systems is presented in the works of researchers from Kazakhstan (Angold & Zharkov 2014; Angold *et al.* 2016). Hydrocyclones for water purification are currently used in almost all sectors of the economy. However, the existing empirical formulas for optimizing the size of structures do not always give clear characteristics (Jabagiyeva *et al.* 2016; Banerjee *et al.* 2017; Vakamalla *et al.* 2017; Xu *et al.* 2017), which means that the relevance of this problem remains.

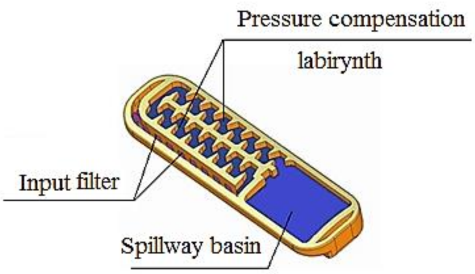


Fig. 2. Labyrinth-type dropper.

Canadian scientists came closest to the solution of water purification (Sabbagh *et al.* 2017), having developed a diagram of the efficiency of a hydrocyclone, which can predict the performance of a hydrocyclone when designing a treatment structure. Some success in this area has been achieved by Russian scientists, whose work presents an analytical model for the classification of particles in hydrocyclone classifiers, which can be used for the design of hydrocyclones (Krokhina *et al.* 2017). In China, when studying the patterns of dropper clogging in a drip irrigation system with a low-quality water source, recommendations for anti-clogging measures were developed (Wang *et al.* 2022). The results of the studies showed that the characteristics of clogging were related to the types of droppers, sediment content, and sediment particle size. A high concentration of deposits means that the droppers are more likely to be completely blocked, and the overall development of blockage will be short and fast. However, when treating water with a lower concentration of deposits, the probability of complete clogging of droppers decreases, and the clogging process is uniform and slow. The clogging position of large flow channel droppers occurs at the beginning and middle of the drip irrigation tape, and internal clogging usually occurs at the inlet. Small-sized channel emitters are concentrated at the head and end of the drip irrigation tape, and internal blockage usually occurs in the slow-moving zone of the labyrinth channel, for example, on the inlet enclosure. The issues of the movement of solid particles in the hydrocyclone chamber are considered in many works, in particular, in papers concerning classifier hydrocyclones (Yufin 1974; Abduramanov & Abduramanov 2006; Yakubovich & Meshcheryakov 2012), thickener hydrocyclones (Yakovlev & Kalitsun 1972; Skirdov & Ponamarev 1975; Fominykh 1985), including the distribution of the solid phase between the discharge holes of the apparatus (Romenskii 1971; Abramov 1982; Kasymbekov 1999), as well as vacuum hydrocyclones (Povarov 1971). The theoretical aspect of the problem is analyzed in the works of Matkovskii (1966), Naidenko (1976) and Romenskii (1971), also for hydraulic transport of the primary product (Rietema 1961). There are also some reports about water quality around the world (Fatih *et al.* 2021; Alwin *et al.* 2023; Gartsiyanova *et al.* 2023). In all these works, a cylindrical conical apparatus with an inlet pipe located perpendicular to the longitudinal axis is taken as a model of a hydrocyclone, and the drain pipe is immersed up to the beginning of the conical part. The shape of the inlet hole is round or rectangular. To date, there have been no proposals regarding the angle of deviation of the inlet pipe along the vertical plane, i.e., it has not been established what effect the angle of deviation of the inlet pipe has on the classifying ability of the hydrocyclone or the degree of sediment thickening in the sand pipe. The relevance of these issues is growing from year to year and entire chapters of the available books are devoted to the problems of hydrocyclone flows (Naidenko 1981; Kryazhevskikh & Kryazhevskikh 2000; Zhurba 2003). Improving the quality of water purification is aimed at eliminating clogging of the elements in drip irrigation systems and increasing their service life when using low-quality water sources. To improve the quality of water purification used on drip irrigation systems, it is necessary to use a hydrocyclone. The purpose of the study was to evaluate the possibilities of using a hydrocyclone with adjustable parameters to improve the quality of water purification in drip irrigation systems.

MATERIALS AND METHODS

The methodology for the study of hydraulic and hydrodynamic processes in a hydrocyclone was developed based on generally accepted norms and rules for conducting experiments. The repetition of experiments was threefold.

The order of the experiments included:

a) Pressure distribution at the characteristic points of the hydrocyclone;

b) Distribution of flow rates between discharge holes;

c) Distribution of liquid density in the hydrocyclone chamber.

Materials used

- Logbook;
- Pressure gauge for working pressure;
- Goniometer (for measuring the angle of the inlet nozzle);
- Measuring cup (the volume received from each discharge hole was measured);
- Stopwatch (for determining the cycle running time);
- Laboratory scales (the mass of accumulated solid sediments from each discharge pipe was weighed);
- Valve (for regulating the pressure of the source fluid);
- Sieve (for classification of granulometric composition).

The flow rate of the purified liquid was measured using a measuring tank, and the flow rate of the pulp through the sand pipe was measured using a volumetric method. The study was carried out at the experimental site of the

Kazakh Scientific Research Institute of Water Management. The experimental hydrocyclone pumping unit (Abduramanov 2012) is shown in Fig. 3.

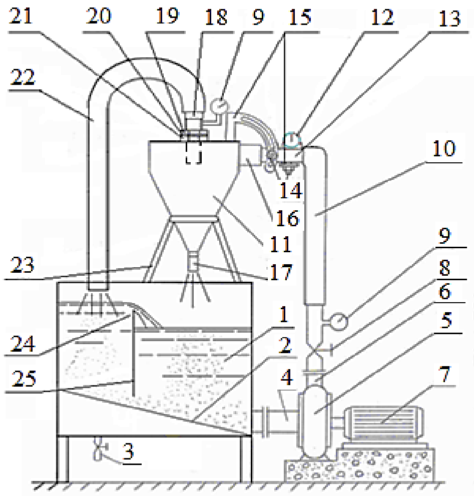


Fig. 3: Schematic diagram of an experimental hydrocyclone pumping unit; 1: tank; 2: guide rail; 3: drainage; 4: pump suction pipe; 5: pump; 6: pump discharge pipe; 7: electric motor; 8: valve, 9: pressure gauge; 10: discharge hose; 11: hydrocyclone; 12: goniometer; 13: nozzle; 14: mounting bolt; 15: bracket; 16: inlet pipe; 17: sand pipe; 18: drain pipe; 19: lock nut; 20: sealing gasket; 21: nut; 22: drain pipe hose; 23: racks; 24: spillway; 25: partition.

To establish the optimal technological and design parameters of the hydrocyclone, the following definitions were established at the test bench:

a) For single-phase liquid:

- Determination of the influence of the angle of deviation along the vertical and horizontal plane of the inlet pipe with different types of cross-sections on the distribution of pressures at characteristic points of the hydrocyclone pumping unit and water flow through the discharge holes of the hydrocyclone;

- A study of the influence of the depth of immersion of the drain pipe into the hydrocyclone chamber on the distribution of fluid flow through the discharge holes of the apparatus.

b) For two-phase liquid:

- Regulation of the solid phase exiting through the discharge holes under conditions of change of the above elements.

To establish these characteristics, a research methodology was compiled for studies conducted in laboratory conditions based on the requirements of technical means of water supply. The hydrocyclone pumping unit was mounted based on a 1.5-K-6 type centrifugal pump (5), which had a valve (8) on the discharge line to regulate the pressure of the source liquid with the pressure gauge (9). The pressure hose (10) was connected to the nozzle (13) and had three types of cross-sectional configurations (round, square, and semicircular). To change the angle of inclination along the horizontal and vertical plane of the latter, the brackets (15) and fixing bolts (14) with a goniometer (12) were used. The nozzle (13) was inserted into the inside of the inlet pipe (16) made of elastic material and tangentially glued to the cylindrical part of the hydrocyclone (11). The inner side of the tip of the hydrocyclone cone (11) had a screw thread, for screwing and changing sand pipes (17) with different hole diameters. The lower part of the drain pipe (18) had an external screw thread for screwing into the nut (21) welded in the center of the lid of the hydrocyclone, thereby immersing into the cavity of the hydrocyclone (11), and for the density of fastening, a sealing gasket (20) was placed and tightened with a lock nut (19). The purified water was drained through the hose of the drain pipe (22) into the second compartment of the tank (1) with a partition (25), where it filled the tank and poured through the spillway (24) into the first compartment. The bottom of the tank contained a guide bar mounted at an angle to the suction line of the pump (5) to direct solid particles to the suction pipe of the pump (4). The tank (1) was emptied using drainage (3).

The experiments were carried out as follows. The tank (1) was filled with water which contained solid particles of various fractions, and for the reliability of experimental data, water with solid deposits was thoroughly agitated before each sampling. By turning on the pump (7) with water pressure control performed by the valve (8), the initial suspension was supplied through the inlet pipe (16), which could change the angle of inclination. Further, the liquid tangentially entered the cylindrical-conical part of the hydrocyclone (11) where acquiring a helical movement under the action of centrifugal force, solid particles were thrown against the wall of the conical part and removed through the sand pipe (17). Afterward, the purified water rising from the ascending stream was diverted through the drain pipe, which has the possibility of immersion at a depth of h_{dr}. By changing the angle of inclination of the inlet pipe along the vertical plane θ = 0º...6º and along the horizontal plane φ = 0º...2°, nozzles of round, square and semicircular cross-section alternately changed by an alteration in the depth of immersion of the drain pipe and pressure at the inlet to the hydrocyclone at P = 0.1; 0.3; 0.5 kgf cm^2. Besides, sand pipes with hole diameters d = 18 mm; 11 mm; 9 mm were changed (Table 1).

Table 1. Changes in the parameters of the hydrocyclone during experimental studies

Name	**Parameters**
1	**2**
Configuration of the inlet nozzle	Round, square, semicircular
Changing the angle of the inlet pipe along the vertical plane, θº	0º, 2º, 4º, 6º
Changing the angle of the inlet pipe along the horizontal plane, φº	0º, 2º
Changing the depth of immersion of the drain pipe, $a_c = \frac{h_{\mathrm{imm}}}{\mathrm{H}_{cy}}$	0, 0.77, 1
Changing the diameter of the sand pipes, d_{sand}, mm	9, 11, 18

Performing the water sampling through the drain and sand pipes at the same time, the flow rate was determined over some time:

$$Q_{\mathrm{dr}} = \frac{W_{\mathrm{dr}}}{t} \tag{1}$$

where W_{dr} is the volume of water going through the drain pipe, l;
t is the time interval, s.

$$Q_{\mathrm{sand}} = \frac{W_{\mathrm{sand}}}{t} \tag{2}$$

where W_{sand} is the volume of water going through the sand pipe, l;
t is the time interval, s.

Total flow rate:

$$Q_{\mathrm{in}} = Q_{\mathrm{dr}} + Q_{\mathrm{sand}} \tag{3}$$

In experiments with a two-phase liquid, after finding the volume of water going through the discharge holes, the solid phase was collected from the bottom of the measuring tank and filled into aluminum buckets for drying in an electric stove. After drying the solid phase, the resulting portion of the solid phase, corresponding to the experiment, was sifted through a sieve to establish the granulometric composition δ from each discharge pipe.
The density of the liquid from each hole was determined according to a well-known formula. For the drain pipe:

$$\rho_{\mathrm{dr}} = \frac{m_{\mathrm{dr}.l} + m_{\mathrm{dr}.s}}{W_{\mathrm{dr}}} \tag{4}$$

where $m_{dr.\,l}$, $m_{dr.\,s}$ are the masses of liquid and sediment extracted from the drain pipe.

For the sand pipe:

$$\rho_{\mathrm{sand}} = \frac{\text{т}_{\mathrm{sand}.l} + m_{\mathrm{sand}.s}}{W_{\mathrm{sand}}} \tag{5}$$

where $m_{sand\,l}$, $m_{sand\,s}$ are the masses of liquid and sediment extracted from the sand pipe.
The density of the liquid at the entrance to the hydrocyclone:

$$\rho_{\text{in}} = \frac{m_{\text{dr}.l.} + m_{\text{dr}.s.} + m_{\text{sand}.l.} + m_{\text{sand}}}{Q_{\text{dr}} + Q_{\text{sand}}} \quad \textbf{(6)}$$

The pulp consistency was determined using the formula:

$$C = S : L \quad \textbf{(7)}$$

where S is the solid phase;
L is the liquid phase.
The possibility of changing the angle of inclination along the horizontal θº and vertical φº planes (Fig. 4).

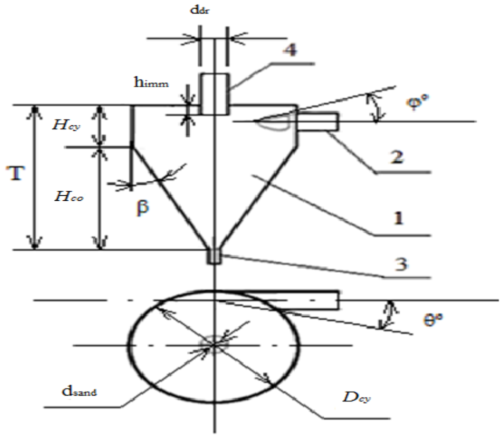


Fig. 4: Low-pressure hydrocyclone; T is the height of the cyclone; H_{cy} is the height of the cylinder; H_{co} is the height of the cone; h_{dr} is the depth of immersion of the drain pipe; φº is the angle of inclination of the inlet pipe along the vertical plane; θº is the angle of inclination of the inlet pipe along the horizontal plane.

The main dimensions of the hydrocyclone are shown in Table 2.

Table 2. Main dimensions of the hydrocyclone.

Model No.	The main dimensions of the hydrocyclone						
	D_{cy} mm	H_{cy}, mm	H_{co} mm	β°,0	d_{in}, mm	d_{dr}, mm	d_{sand}, mm
1	184	110	295	15	36	36	9
2	-//-	-//-	-//-	-//-	-//-	-//-	11
3	-//-	-//-	-//-	-//-	-//-	-//-	18

Measurement errors and inaccuracies in the formulation of experimental studies may arise due to the leakiness of individual connections of elements of a hydrocyclone pumping unit, inflections of pressure hoses, errors in pressure gauges, inaccuracy of calibration of instruments and apparatus, the inexperience of the observer and the influence of external factors (fluctuations in temperature, atmospheric pressure, etc.). Such errors were excluded during the experiments.

RESULTS

We looked at the value of the relative flow of liquid through the sand hole of a pressure hydrocyclone with a round, square, and semicircular shape of the inlet hole for different values of the angle of deflection of the inlet pipe along the vertical (θ^0) and horizontal (φ^0) planes.
We established that:

- By an elevation in the specific kinetic energy of the flow at the entrance to the hydrocyclone $V_{\text{in}}^2/g(H_1+p)$, the relative flow rate $\left(\frac{Q_{\text{sand}}}{Q_{\text{in}}}\right)$ of the sand hole will decline, asymptotically approaching the abscissa axis;
- For each value, the $[V_{\text{in}}^2 g(H_1+P)] \leq 0.01$ value Q_{sand} and Q_{in}decreases by elevating depth of immersion of the drain pipe;

- An elevation in the angle of internal inclination of the inlet pipe to the walls of the hydrocyclone (φº) leads to a drop in the relative flow rate of the sand hole;

- The minimum flow rate of the sand hole is easily achieved by the semicircular shape of the inlet pipe$[V_{\text{in}}^2 g(H_1 + P)] \geq 0{,}025$; the round hole in this respect is the worst-case scenario; the square shape of the inlet hole is in the intermediate position;

The changes in fluid flow rates were studied through the discharge pipe of a pressure hydrocyclone at different depths of its immersion for round, square, and semicircular shapes of the inlet, as well as at different angles of deflection of the inlet pipe along the vertical (θº) and horizontal (φº) planes.

We also established that:

- By an elevation in the specific kinetic energy of the flow at the inlet to the hydrocyclone $V_{\text{in}}^2/g(H_1 + p)$, the relative flow rate of the drain hole $\frac{Q_{\text{dr}}}{Q_{\text{in}}}$ upraises by all forms of the inlet hole and the depth of immersion of the drain pipe;

- For each value, the $V_{\text{in}}^2/g(H_1 + p)$ value $Q_{\text{dr}}/Q_{\text{in}}$ increases by the elevating depth of immersion of the drain pipe of the hydrocyclone. This effect is especially noticeable at the angles of deflection of the inlet pipe within θ = 2º...4º in the vertical plane;

- When the drain pipe is not immersed, the vertical angle of deviation of the inlet pipe θ = 6º causes the smallest drain flow at φ = 0º while elevating in the horizontal deviation by an angle φ = 0º ...2º sharply increases $Q_{\text{dr}}/Q_{\text{in}}$;

- The relative flow rate of the drain pipe $\left(\frac{Q_{\text{dr}}}{Q_{\text{in}}}\right)$ for the semicircular inlet hole at θ =2º is the highest flow rate for all values $V_{\text{in}}^2/g(H_1 + p)$.

Experimental results have been obtained on the quantitative and qualitative redistribution of the solid phase between the discharge holes of a hydrocyclone by an inlet pipe of round, square and semicircular shape with a different deviation (in degrees) of the inlet tangential pipe along the vertical plane. We established that the best clarification (classification) occurs in a hydrocyclone with a semicircular shape of the inlet pipe hole. Square and round holes are less effective (the axis of the inlet pipe is perpendicular to the longitudinal axis of the hydrocyclone). The angle of inclination of the inlet pipe in the vertical plane within θ = 2º ...4º gives a positive effect, while outside this limit, the results of separation of the hydraulic mixture are observed to be less effective. The lowest drain density and the highest density of the sand hole product occur when the drain pipe is immersed up to the cut plane of the cylindrical and conical parts of the hydrocyclone chamber. As a result of experimental studies, theoretical conclusions have been substantiated showing that the control of technological processes of classification can be effectively carried out by elevating the depth of immersion of the drain pipe into the hydrocyclone chamber.

DISCUSSION

We present the results of experimental studies on the distribution of the solid phase between the discharge holes of a hydrocyclone with an inlet pipe of round, square and semicircular shape with different deviations of the inlet tangential pipe along the vertical plane.

Figs. 5-8 show the clarification distribution diagrams of the processed hydraulic mixture in a hydrocyclone with various shapes of the inlet section: a) round; b) square; c) semicircular, at θº = 0º ...6º. The other parameters are the same: φº = 0º; a_c = 1; P = 0.5 kgf/cm^2.

Experimental data were obtained for three cases of immersion of the drain pipe:

a) The drain pipe is not immersed and a_c = 0;

b) The drain pipe is immersed to the lower edge of the inlet pipe, a_c = (0.5...0.7) H_{cy};

c) The drain pipe is immersed up to the interface plane of the cylindrical and conical parts, a_c = 1.

A systematic analysis of experimental data on the redistribution of the solid phase between the drain and sand holes has shown the following:

1) By the horizontal arrangement of the inlet pipe (Fig. 5), the main part of the solid phase is concentrated at the mouth of the cone and flows through the sand hole in the form of pulp; the pulp density depends on the content of the solid phase of the hydraulic mixture entering the hydrocyclone chamber. Thus, at ρ_{in} = (1.005...1.010) g L^{-1}, the pulp density in the sand hole varies within ρ_{sand}= (1.038...1.067) g L^{-1}; under the same conditions, the density of the liquid going through the drain hole changes very slightly and differs little from the density of water ρ_{dr} = (1.0003...1.0007) g L^{-1}; the best clarification is obtained with a semicircular shape of the inlet section;

2) When the inlet pipe is inclined (Figs. 6-8) along the vertical plane (θº = 2º...6º), the best clarification is given by a hydrocyclone with a deviation angle of θº = 2º ...4º with a semicircular shape of the inlet pipe holes; the square shape of the inlet hole gives results very close to the results of the semicircular shape of the hole; notably, the round shape of the inlet pipe does not give the best results compared to the other cross-section shapes considered;

3) A comparison of the results of experiments on the exit of the solid phase into the drain pipe (Fig. 9) shows that the cleaning quality improves when the drain pipe is immersed up to the interface plane of the cylindrical and conical parts of the hydrocyclone and by the semicircular shape of the inlet hole when the angle of inclination of the inlet pipe is within θº = 2º...4º. This is explained by the fact that with the deeper immersion of the drain pipe, the degree of symmetry of the surface of zero axial velocities (ZAV) upraises, while the size of the boundary grains drops. By an elevation in the length of the immersed part of the drain pipe, the hydrocyclone flow becomes more organized: the total surface area of the ZAV is minimized and occupies an axial area with high tangential velocity values, where the classifying ability of the cyclone flow is also high. At the same time, the relative drain flow upraises due to a drop in the relative flow going through the sand hole. A higher organization of the cyclone flow makes it possible to improve the technological process of separating water from sediments by reducing the flushing flow through the sand hole and elevating the flow of purified water flowing through the drain pipe.

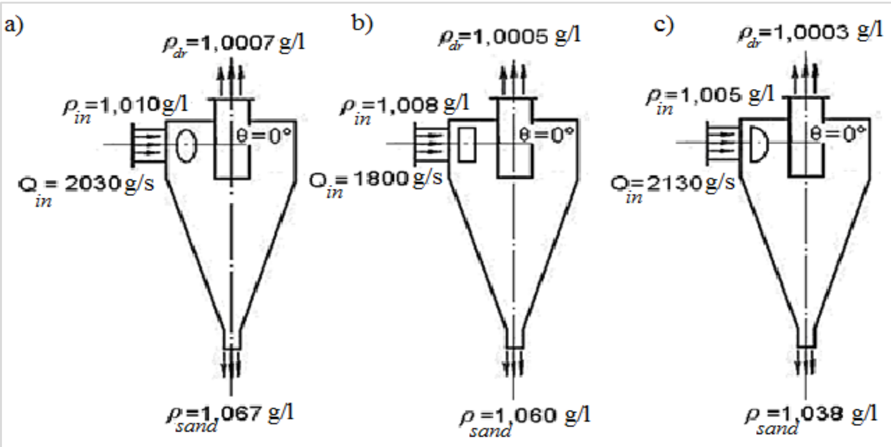


Fig. 5. A diagram of the clarification of the treated pulp in a hydrocyclone with various shapes of the inlet section, at a_c = 1; θ = 0°; φ = 0°; P=0.5 kgf/cm^2; a) by a circular section of the inlet pipe; b) by a square section of the inlet pipe; c) by a semicircular section of the inlet pipe.

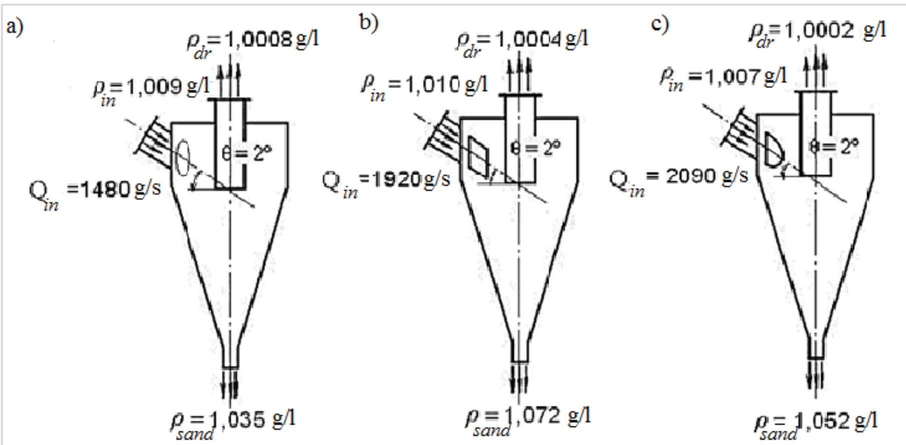


Fig. 6: A diagram of the clarification of the treated pulp in a hydrocyclone with various shapes of the inlet section, at a_c = 1; θ = 2°; φ = 0°; P=0.5 kgf/cm^2; *a)* by a circular section of the inlet pipe; b) by a square section of the inlet pipe; c) by a semicircular section of the inlet pipe.

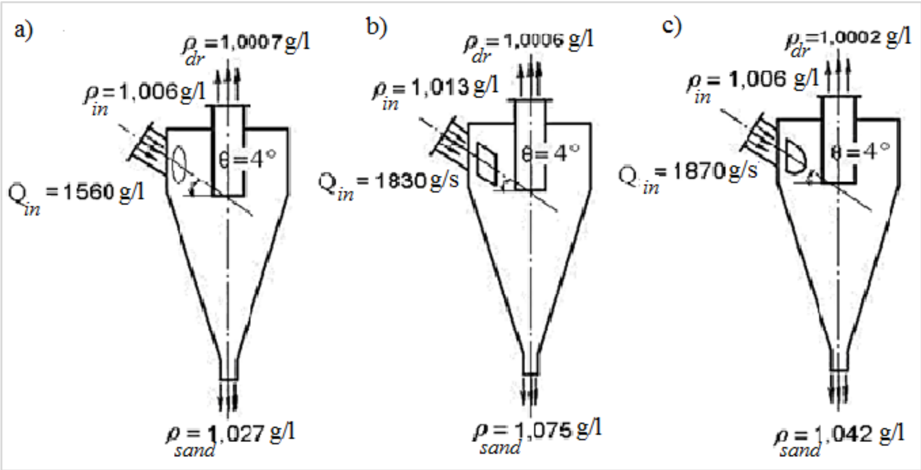


Fig. 7: A distribution diagram of pulp consistency in a hydrocyclone with various shapes of the inlet section, at a_c =1; θ = 4°; φ = 0°; P= 0.5 kgf/cm^2; a) by a circular section of the inlet pipe; b) by a square section of the inlet pipe; c) by a semicircular section of the inlet pipe.

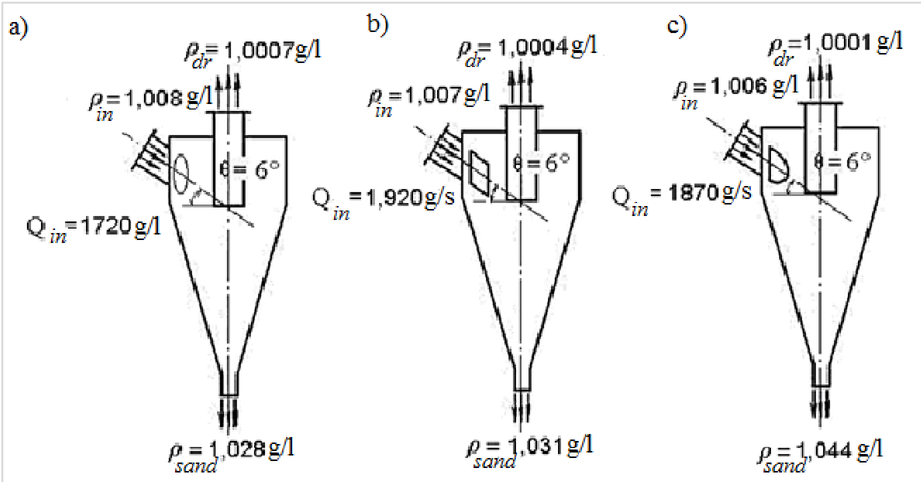


Fig. 8: A distribution diagram of pulp consistency in a hydrocyclone with various shapes of the inlet section, at a_c =1; θ = 6°; φ = 0°; P= 0.5 kgf/cm^2; a) with a circular section of the inlet pipe; b) with a square section of the inlet pipe; c) with a semicircular section of the inlet pipe.

Thus, two ways of improving the axisymmetry of the zero-velocity surface (process control) are clearly outlined:

1) Manufacture of hydrocyclones with multiple inlet pipes;

2) The discharge pipe is adjustable with the maximum depth of immersion to the interface plane of the cylindrical and conical parts of the hydrocyclone.

In practice, the first way is used mainly when the hydrocyclone chamber is located at the bottom of a water source (channel, river, etc.), and the second in non-immersed versions of the hydrocyclone (above the water source). Bing *et al.* (2020) developed some new hydrocyclones and by replacing one inlet hole with several ones, as well as reducing the width of the inlet hole, they increased the efficiency of separation of solid particles in the hydrocyclone.

In our design, we did not reduce the width of the inlet hole, however, changed the configuration of the inlet pipe (round, square, semicircular), albeit the cross-sectional area remains the same. We also changed the angle of inclination along the vertical and horizontal planes of the inlet pipe.

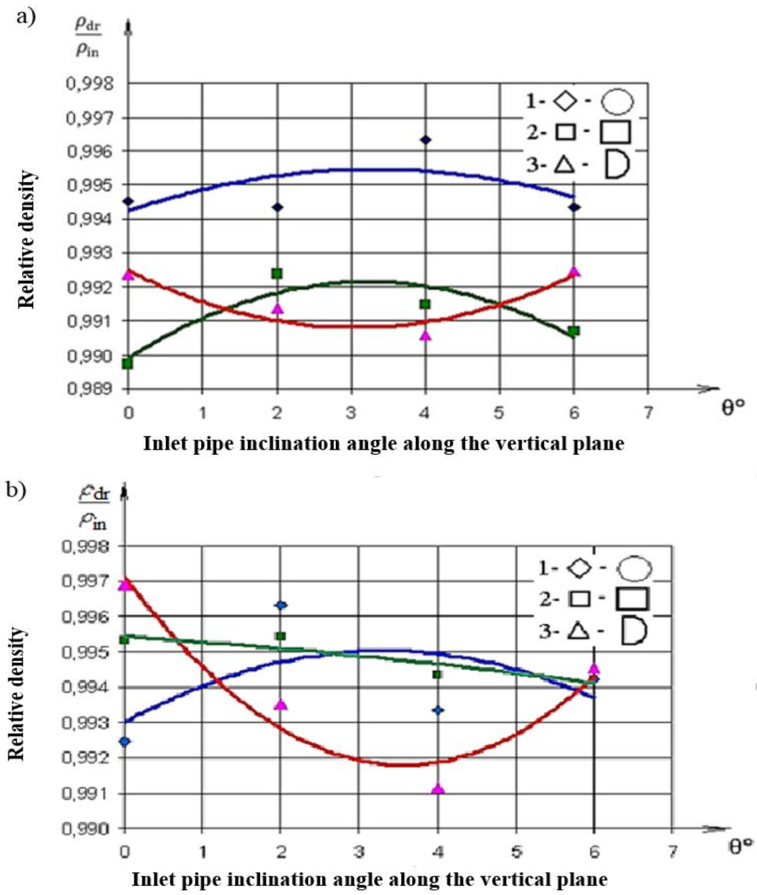
Fig. 10 shows a graph comparing the separation efficiency of four Liu Bing hydrocyclones with our hydrocyclone design. Since our hydrocyclone is used for pretreatment in drip irrigation systems, we used solid particles with a diameter of 30 microns or more. According to Fig. 10, the quality of irrigation water treatment of our design is approximately identical to the designs of Bing *et al.* (2020), and by an elevation in the diameter of solid particles, the quality of cleaning only improves.

CONCLUSION

In this studyr, we reviewed the design of hydrocyclones and hydrocyclone pumping units, as a result of which we found that their designs are becoming more knowledge-intensive and complex due to the desire of manufacturers to simultaneously implement several technological processes (multifunctional designs) at a higher level in one device. Hydrocyclones have found application in new areas of agricultural production. There has been a constructive fusion of a hydrocyclone with a jet apparatus, a centrifugal pump, a flotation device, a filter, a sump, and other devices. All this shows the relevance of research on the control of technological processes in hydrocyclone and its pumping units, especially in the field of agricultural water supply and irrigation of pastures. Quantitative and qualitative results were obtained on the redistribution of the solid phase between the discharge holes of a hydrocyclone with different inlet shapes (round, square, and semicircular) at different angles of inclination to the plane of the lid of the apparatus in a perpendicular direction:

- The angle of inclination of the inlet pipe in the vertical plane (the vertical location of the hydrocyclone in the space with the sand hole down) gives a positive effect within 2°...4°, while outside this limit, the results of the separation of the hydraulic mixture will be less effective;
- The density of the product of the sand hole will be the highest (the drain density will be the lowest) by the immersed position of the drain pipe up to the plane of the connection of the cylindrical and conical parts of the hydrocyclone;
- The best clarification of the treated water takes place in a hydrocyclone with a semicircular shape of the inlet pipe hole.

Based on the study results, new designs of hydrocyclone and its pumping devices were developed in which the technological process is regulated by the shape of the inlet pipe hole.



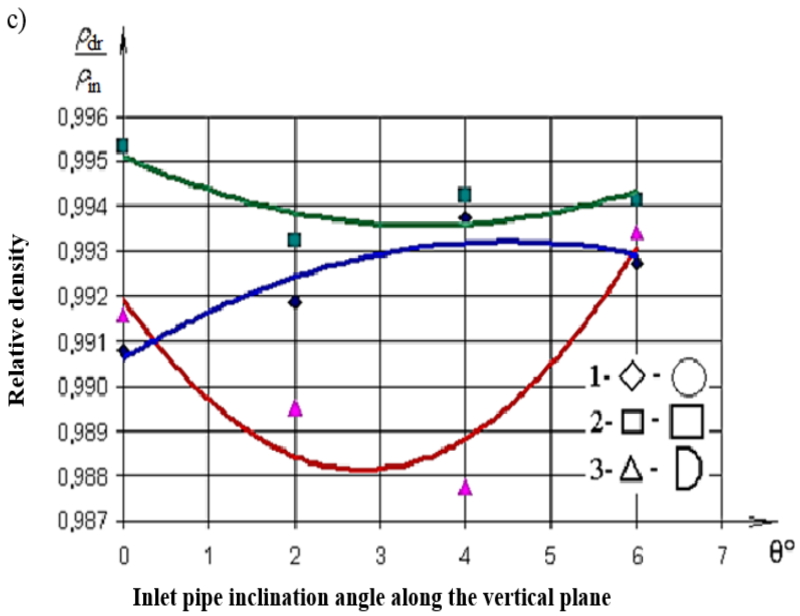


Fig. 9. Dependency graphs for various forms of the inlet hole; a) not immersed drain pipe; b) the drain pipe is immersed to the lower edge of the inlet pipe; c) the drain pipe is immersed up to the interface plane of the cylindrical and conical parts $\frac{\rho_{\mathrm{dr}}}{\rho_{\mathrm{in}}} = f(\theta^0)$.

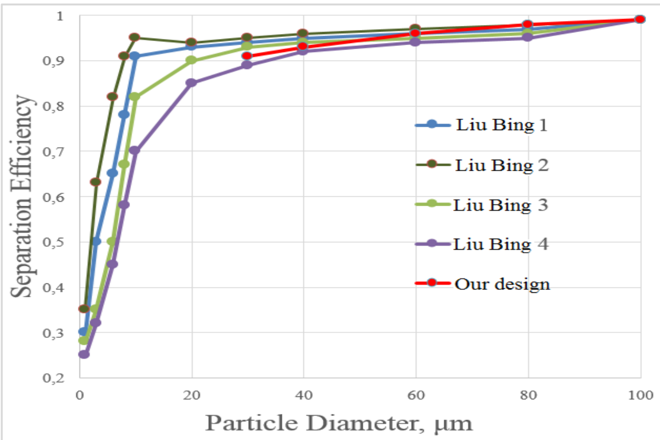


Fig. 10. Comparison of the separation efficiency of four Liu Bing hydrocyclones with that designed in this study at different particle sizes.

An analysis of the studies conducted in this field exhibited that to solve this problem, it is necessary to develop and further research advanced resource-saving technologies for water purification from mechanical impurities and its rational use, as well as for the creation of highly efficient multi-purpose devices capable of successfully performing basic water treatment operations like impurity capture, pulp thickening, and removal of the resulting sediment. The analysis also displayed that using hydrocyclone and its installations are as close as possible to performing this task. Due to relatively low costs for the construction and operation of these devices and installations, this will allow for obtaining significant cost savings, increasing the efficiency of irrigation water purification and the service life of the equipment.

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