Investigation of cylindrical hydrocyclone for emulsion separation

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Abstract. Experimental studies of velocity and pressure fields in a cylindrical hydrocyclone to separate emulsions with a low content of light impurities (not more than 1%) are carried out. The obtained data enable us to conclude that in a cylindrical hydrocyclone optimum conditions for the separation of liquid particles are provided.

Currently, implementation of highly efficient new generation centrifugal separators to separate liquid and gas heterogeneous systems as applied to the treatment of wastewater and gas emissions from fine particles is of relevance [4, 6, 7, 9, 10].

To carry out these processes, various types of equipment are used, which differ not only in the principle of action, but also by design. One of the effective devices for the separation of liquid heterogeneous systems is hydrocyclone.

Hydrocyclones are notable for their low cost, high productivity, simplicity of design, reliability and durability, absence of unacceptable defects, and low material consumption [5,6,8,11,12].

The hydrocyclone type devices have only recently been widely used for the separation of systems with an unstable composition of the dispersed phase, such as liquid-liquid. This is due to the complex mechanism of the separation process of emulsion type liquids, as well as the lack of accurate methods for calculating devices of this type.

The main difficulty of emulsion separation compared with suspensions is a significantly smaller difference in the densities of the components that make up the system. At the same time, for separating emulsions in a hydrocyclone, the movement of the dispersed phase can be directed both from the periphery to the center, and vice versa, which imposes additional requirements on the device’s design. However, most of the known designs of hydrocyclones for separation of emulsions practically do not differ from hydrocyclones for separation of suspensions.

Even though the design and principle of operation of the hydrocyclone was developed and implemented about 100 years ago, the basic principles of work have not changed. The degree of necessity and relevance of this device is high today. That is why the research is ongoing and new designs are being developed [4,6,8,10].

As already noted, the previous studies were performed using standard designs of hydrocyclones, which had a larger diameter of the upper drain pipe compared to the lower sludge pipe, and in fact there are no studies of hydrodynamics of hydrocyclones with a low flow rate through the upper drain pipe.
Figure 1. Dependence of static pressure on the cylindrical hydrocyclone’s radius.

The technological requirements for hydrocyclone-type devices for separating emulsions with a low content of light impurities (not more than 1%), which include oil-containing wastewater from industrial enterprises, determine the removal of the main amount of purified liquid through the lower drain pipe, and only a small part of the liquid enriched with light impurities - through the upper drain hole [10]. This is since the ratio of the flow volumes must commensurate with the ratio of concentrations of the separated phases. The lack of data on the hydrodynamics of hydrocyclones operating under such conditions predetermined the need for the experiments described in this paper.

It is established that the tangential component of the fluid velocity, which is 90-95% of the total velocity, has the main influence on the separation process in a hydrocyclone. Therefore, when conducting research, an important task is to study the distribution of the tangential velocity in the device.

In this work, experiments were carried out to study the distribution of static pressure and tangential component of the velocity along the radius in four horizontal sections of a cylindrical hydrocyclone. The experiments were carried out on a setup consisting of a pump, a container for the initial liquid, a transparent hydrocyclone model, pressure gauges, pipelines and valves to change the supply pressure and the amount of water supplied. The experimental setup could work both in a closed circuit and in countercurrent mode.

The technique for measuring velocity and pressure fields in a hydrocyclone is similar to that described previously [1, 10].
To obtain reliable results, experiments for each condition were performed at least three times. The graphs show only the averaged values of the obtained values.

It is known that emulsion type liquids can be separated using hydrocyclones of small diameters and sizes. The investigated cylindrical hydrocyclone had a diameter of 50 mm and a length of 350 mm. The liquid is discharged through the upper drain pipe and two diametrically opposite located outlet pipes. The diameters of these pipes were selected based on the task of the required ratio of costs. During the experiments, the task was to cover the unexplored region from the point of view of the flow distribution over the drains depending on the content of light impurities in the emulsion and to consider changes in the flow hydrodynamics with a change in the ratio between the drain pipes.

Figures 1, 2 show the dependences of the distribution of static pressure and tangential velocity during 5.03% removal of the liquid from the total flow through the upper drain pipe. This cost ratio was established with a diameter of two tangentially opposite inlet pipes of 7.5 mm each, a diameter of two lower drain pipes of 11 mm, a diameter of the upper drain pipe of 3 mm. During the experiments, the pressure at the inlet to the hydrocyclone \( P_{\text{in}} \) was set equal to 0.105 MPa.

Figure 1 shows the dependence of static pressure at different sections along the hydrocyclone’s radius. The static pressure increases from the axis to the hydrocyclone’s wall, and its value remains constant over the entire height of the device at equal radii.

The nature of the tangential velocity change along the radius and height of the device is shown in Figure 2. The experiments showed that for this design of the hydrocyclone the presence of a maximum tangential velocity in the near-wall region is characteristic. When moving away from the inlet pipe, the tangential velocity component at the wall of the hydrocyclone decreases, and in the paraxial zone it remains constant within the accuracy of the measurement.

Based on the results of the foregoing, one can conclude that the profile of the tangential flow velocity in a cylindrical hydrocyclone consists of three areas: central, axial and wall. In the central zone of the device, the value of the tangential velocity remains constant along the radius, but the zone of constant tangential velocity increases with distance from the upper drain pipe.
In the near-wall zone, an increase in the tangential velocity is observed, especially in the upper part of the device, where the conditions of emulsion entering still affect the surroundings. In the area between the drain pipe and the device’s body, the tangential velocity of the fluid flow is stabilized into a certain constant height profile.

An analysis of the tangential velocity variation along the radius and height in a cylindrical hydrocyclone [4] showed that, with a decrease in the flow rate of the central upward flow directed to the upper drain hole, the tangential velocity decreases and becomes lower than its average value over the cross section.

Thus, a comparative analysis of the data obtained from previous experiments made it possible to establish that in a cylindrical hydrocyclone with a low flow rate through the upper drain, the tangential component of the fluid velocity is closer to quasi-solid rotation, and in a cylindrical-conical hydrocyclone this profile is closer to quasipotential rotation [10].

Considering the stability criterion for turbulent flow, proposed by Rayleigh, it can be said that the presence of a tension field with a negative gradient (quasi-solid rotation in a cylindrical hydrocyclone) helps to maintain this value and, therefore, will contribute to the stability of the flow in the radial direction. Thus, the presence of a tension field with a negative gradient ensures the conservation or even increase in the angular momentum, which ultimately leads to the preservation of the flow stability in the radial direction and suppression of turbulence [2,3].

The presence of a stress field with a positive gradient (quasipotential rotation in a cylinder-conical hydrocyclone) determines the occurrence of a negative angular momentum, and the latter leads to a decrease in the stability of the swirling flow, i.e. to the development of turbulence. In addition to the direction of the stress gradient, the numerical value of the stress gradient has a great influence on the stability of the flow. The presence of a large stress gradient should prevent the development of transverse fluctuations in the flow and will stabilize the flow.

Based on the results of experiments obtained in laboratory studies, we can conclude that in a cylindrical hydrocyclone, due to the stability of the flow in the radial direction, optimal conditions will be ensured for separation of liquid particles, i.e. the separation efficiency will be higher.

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