Research of equipment for cleaning oil-containing wastewater

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Abstract. The problems of cleaning emulsion-type liquids with a low content of light impurities, which include oil-containing wastewater of industrial enterprises, are considered. Ways are proposed to improve the design of a cylindrical-conical hydrocyclone for the process described above. The experimental studies of the velocity and pressure fields in a cylindrical-conical hydrocyclone indicate the promise of using it for the separation of oil-containing wastewater with a low concentration of light impurities.

Increased attention to hydrocyclones for separation of emulsion-type liquids has arisen due to environmental problems, since almost all industrial enterprises have wastewater containing oil, and grease.

Nowadays, this separation is mainly carried out by long-term sedimentation in tanks - settlers of large volume. In sedimentation tanks, the working factor is the difference in the densities of the components. It is more expedient to use the difference in densities in a centrifugal field, where the separation factor is several orders of magnitude higher.

Hydrocyclones are simple in design, compact, of fairly high performance, defect-free, reliable in operation, cheap to manufacture, and can be located in close proximity to the main technological areas [1-4, 6, 7]. At high temperatures and pressures, hydrocyclones are indispensable because they do not have moving parts and seals.

Particular interest in studying the capabilities of a hydrocyclone for emulsion separation occurs at the second stage of oil production, when various artificial methods are used to intensify it (adding chemical reagents, bypass flooding, etc.). In these cases, the presence of liquid impurities increases, both in the oil itself and in liquids containing oil. The processing of large volumes of liquids contaminated with both mechanical and oil impurities is a real problem when considering environmental problems.

When separating immiscible liquids in hydrocyclones, which includes oil-containing wastewater from industrial enterprises, reliable information on the hydrodynamics of these devices is necessary.

The main attention in research and evaluation of apparatus characteristics is given to experimental methods, since the theory of multiphase systems is complex and not yet sufficiently developed.

The main hydrodynamic indicators are pressure and the tangential component of the flow velocity.

Currently, there are a number of experimental measurement methods: contact or probe (Pitot-Prandtl tubes, multi-channel ball probes, hydromechanical turntables, etc.), probeless (optical, stroboscopic, electrodiffusion, etc.) [1, 5, 8]. The choice of a specific measurement method is
determined by the type of flow, the size of the apparatus under study, the required accuracy of the experiments, and a number of other factors. The introduction directly into the probe flow can in some cases significantly distort the initial flow pattern, which is practically not the case when using probeless methods.

Probeless measurement methods give higher measurement accuracy, and the direct sensing method is much simpler and cheaper, but requires more time. Of the many probes, the smallest measurement error is provided by a transversely stretched capillary tube with special receiving holes. In order to avoid significant measurement errors and flow distortions, a requirement should be provided according to which the "flow blocking factor" should not exceed 5%. The ratio of the area of the full mid-section of the probe to the cross-sectional area of the channel in the plane of the probe is meant by this coefficient. In the case of measuring swirling flows, the use of transversely stretched probes is also justified because there is $V_r$ radial velocity component in them, which the transversely stretched probe does not allow to measure, is negligible in comparison with other components of the velocity vector (tangential). Therefore, measurement errors in this case will be minimal. In this case, the value of the measurement error is determined, as a rule, by the division value of the micromanometer and does not exceed 2.6%.

Given all of the above, for conducting experimental studies, such type of probe as cylindrical pneumometric nozzles was used [8].

With this nozzle, the averaged speed and the averaged flow direction can be measured. The nozzle is a thin long tube with an outer diameter of more than 1 mm. The inner cavity of the tube is divided by a partition 1 into two parts. On one side of the partition, at a distance of 1 mm from it, there are eight holes of 0.23 mm uniformly in a circle in the tube, and one hole on the other side. Such a tube, long and thin, like a string, is usually installed across the flow so that the velocity vector is approximately orthogonal to its axis. By moving the tube along the axis, it is possible to measure the transverse velocity profile in both the forward and reverse current zones.

The experimental setup, measurement technology, and calibration of the measuring probe have been described in detail previously [5, 8].

The technical literature on hydrocycloning reflects processes that occur mainly in a cylindrical-conical hydroclone [1-4]. These devices are simple construction ones consisting of a cylindrical part with a flat cover and a conical part. An inlet pipe is located in the cylindrical part, with the help of which the feed mixture is supplied to the apparatus body. To drain the clarified liquid, a drain pipe is used.

It should be noted that all previous studies were performed on standard designs of hydrocyclones, which had a larger output section of the upper drainpipe in relation to the lower sludge pipe; and there are practically no studies of hydrodynamics of hydrocyclones with a low flow rate through the upper drainpipe [5]. The technological requirements for hydrocyclones for the separation of emulsions with a low content of light impurities (about 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. The lack of data on the hydrodynamics of hydrocyclones operating in such conditions predetermined the need for these studies.

The cylinder-conical hydrocyclone under study had the following geometric dimensions: the diameter of the cylindrical part was 50 mm, the height of the cylindrical part was 50 mm, the diameter of the two tangentially opposite inlet pipes was 7.5 mm, the diameter of the upper drain pipe was 5 mm, and the diameter of the lower pipe was 10 mm. The conical part was a complex conical shape with a taper angle $\alpha_1=30^\circ$ и $\alpha_2=2^\circ$. The pressure at the inlet to the hydrocyclone ($P_{inp}$) was set to 0.15 MPa, 4.3% of the liquid from the total flow was discharged through the upper drain pipe, the fluid velocity was 6.05 m/s.

The accuracy of the experiments depends mostly on the accuracy of the measurement of the primary data. In the conducted studies, it was necessary to establish the position of the receiving hole
in the studied channel. For an axisymmetric channel, this means setting the axial and radial coordinates. The axial coordinate $z$ was determined by measuring the distance from the top cover of the hydrocyclone to the plane of the channel under study. The radial coordinate $r$ of the receiving hole was set using a special coordinate device, which made it possible to determine the radial coordinates of the receiving hole.

Measurements for each investigated section were carried out by successive movement of the receiving hole from the channel wall to its axis. At each considered point of the studied cross section, the probe was rotated around its axis and, at certain intervals of rotation angle change, the readings of the static pressure measured by the probe were taken using the model pressure gauge. For each measured point, a graph was constructed of the dependence of the static pressure of the probe on the angle of rotation of the coordinate device. In connection with a large number of measurements, a program for processing them on a computer was implemented.

The sequential determination of the local values of the static pressure and the tangential component of the total velocity vector for all coordinates $r$ allows us to obtain the corresponding profiles of the static pressure and the tangential component of the fluid velocity for the studied sections $z = 40, 160, \text{ and } 370 \text{ mm}$.

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.

The obtained profiles of the distribution of static pressure along the radius of the hydrocyclone at different $z$ sections are shown in figure 1. An analysis of the results shows that the value of static pressure decreases from the wall to the axis of the apparatus. This dependence is preserved over the entire height of the hydrocyclone within the studied parameters. It should also be noted that the value of static pressure at the same radius at different sections along the height of the apparatus remains constant.

![Figure 1](image_url)  
**Figure 1.** The dependence of static pressure on the radius of the cylindrical-conical hydrocyclone.

The value of the tangential velocity of the fluid increases as it approaches the wall of the hydrocyclone, then it reaches a maximum at a certain radius and begins to decrease; and the nature of the dependence is determined by $z$ parameter (figure 2). The maximum tangential velocity in the cross
section $z = 40$ mm is at a distance of $0.4r$. This section is located in the cylindrical part of the apparatus, where the influence of the inlet section still affects.

![V=f(r)](image)

**Figure 2.** The dependence of the tangential velocity on the radius of the cylinder-conic hydrocyclone.

The studied sections $z = 160$ and $370$ mm are in the conical part of the hydrocyclone. The tangential velocity profile in the axial zone of these two sections corresponds to the nature of the velocity distribution in the cylindrical part of the apparatus. In the near-wall zone, the tangential velocity for its sections in the conical part is somewhat lower. The results obtained are in fairly good agreement with the known data, especially with respect to the velocities in the axial zone of the apparatus [1, 2].

The adequacy of the previously developed program [5] was verified using the experimental data obtained above. Operating and technological parameters were set the same as in experimental studies. The dashed line in figures 1 and 2 shows the calculation results. An analysis of the results indicates a good convergence of theoretical and experimental studies for this type of hydrocyclones.
The results of experimental and field studies indicate the prospects of using a cylindrical-conical hydrocyclone with a low flow rate through the upper drainpipe to separate oil-containing wastewater with a low concentration of light impurities (about 1%).

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