UDC 621.928.37

Determination of hydrocyclone parameters for oil emulsion treatment with forced flow rotation, taking into account changes in rheological properties

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Received: 01.05.2023; Accepted: 15.06.2023
https://doi.org/10.32347/gbdmm.2023.101.0302

Abstract. The object of research is the process of dewatering oil emulsions by using a hydrocyclone with forced flow rotation taking into account rheological properties.

The problem solved in the work is related to production, primary preparation and transportation of oils. The process of oil extraction is accompanied by saturation of the product with water, salts, mechanical particles and light fractions, which requires primary preparation of oil through multi-stage, sometimes long-term, low-productivity processing in order to separate the above-mentioned components. The water content of some deposits, especially marine deposits, is 80%, which makes the process of oil dehydration particularly important for preparing oil for transportation. Among the known methods of dewatering oil emulsions, such as settling, heat treatment, chemical treatment, electrodehydration and centrifugation, the last one allows to significantly influence the separation processes. The essence of the centrifugation process, consists in increasing the rotational speed of the particles of the dispersed phase by replacing the natural force of gravity with a more powerful centrifugal force. The density of water and mechanical impurities is higher than the density of oil, and particles under the action of centrifugal force are pressed against the wall and, coagulating, are removed through the flow separator.

In the course of the work, the main regularities of the process were determinedcentrifugation, namely the rate of sedimentation of the water fraction from the rheological parameters of the emulsion and the kinematic characteristics of the hydrocyclone with forced rotation of the flow. It was established that the dependence of the volume of the water fraction of the oil emulsion is a power function of the second order, and the rate is linear. The settling of a water particle has a linear dependence on the size of the particle. Speed The set speed of settling of water particles of an oil emulsion allows you to calculate the length of the turbine depending on the required performance, speed of rotation and rheological properties.

The developed theoretical provisions of the process of dewatering oil emulsions by using a hydrocyclone with forced rotation of the flow, taking into account the rheological properties, allow designing machines of this type for various conditions of oil production.

Keywords: hydrocyclone, emulsion, dehydration, settling velocity, oil.

INTRODUCTION

The technological processes of oil refining are determined by the quality of the raw materials that enter processing, which, in turn, directly depends on the efficiency of the used methods of its preparation and purification. The modern stage of the development of chemistry and technology of hydrocarbons is characterized by a progressive deterioration of the properties and quality of oils due to an increase in water content, corrosive aggressiveness, the content of sulfur, salts, etc. Therefore, reducing the impact of these negative factors on the separation and transformation of hydrocarbon raw materials is one of the priority areas of science and technology.

Reservoir waters coming from wells of different deposits can differ significantly in composition and concentration of dissolved mineral salts and gas content. When mining with formation water, an emulsion is formed, which should be considered as a mechanical mixture of two insoluble liquids (oil and water), one of which is distributed in the volume of the other in the form of drops of different sizes. The presence of water in oil leads to an increase in the cost of transport due to the growing volumes of the transported liquid and its viscosity increase. Based on experience, the water content in oil should not exceed 10-50 ‰. With a higher water content in the oil entering for processing, the technological mode of operation is disturbed, the pressure in the devices increases, micro-explosions begin, the productivity of the rectification column and heat exchange devices decreases,

The reasons given above point to the need to prepare oil for transport.

The main methods of separating emulsions remain:

- advocacy;
- heat treatment;
- chemical treatment;
- electrodehydration;
- centrifugation.

The last method, centrifugation, consists in increasing the rotational speed of movement of particles of the dispersed phase by replacing the natural force of weight with a more powerful centrifugal force; the density of water and mechanical impurities is higher than the density of oil, and particles under the action of centrifugal force are pressed against the wall and, coagulating, flow down. Existing installations that use the centrifugation method are low-performance, complex, expensive, and have not been widely used in industries [1]. The main reason for this situation is the cyclic operation of centrifuges, which makes the centrifugation process extremely difficult from the point of view of cleaning from sediment [3-6]. The use of flow-through hydrocyclones solves this problem, but at the same time, the rotation speed of the emulsion is lost, which makes the process inefficient. Existing designs of vortex hydrocyclones,

This problem is solved by using a hydrocyclone to process an oil emulsion with forced rotation of the flow[.

To solve the task, there is no method for calculating the parameters of a flow-type hydrocyclone that takes into account the rheological characteristics of the emulsion (density, viscosity).

PURPOSE OF THE WORK

Therefore, the purpose of the work is to study the process of dewatering oil emulsions by using a flow-type hydrocyclone with forced rotation of the flow, taking into account rheological properties. This goal can be achieved by solving the following tasks:

- develop a schematic diagram of the device;
- analytically describe the process of oil emulsion separation under the action of centrifugal forces;
- on the basis of the obtained regularities, determine the main parameters of a flow-type hydrocyclone with forced rotation of the flow.

The object of researchis a process of dewatering oil emulsions by using a flow-type hydrocyclone with forced flow rotation taking into account rheological properties.

When performing the work, the following were used:

– analytical method of research in the process of oil emulsion separation under the action of centrifugal forces;

- a grapho-analytical research method for determining the parameters of a flow-type hydrocyclone with forced rotation of the flow.

RESULTS AND DISCUSSION

Therefore, a new design of a hydrocyclone was proposed (Fig. 1), which allows

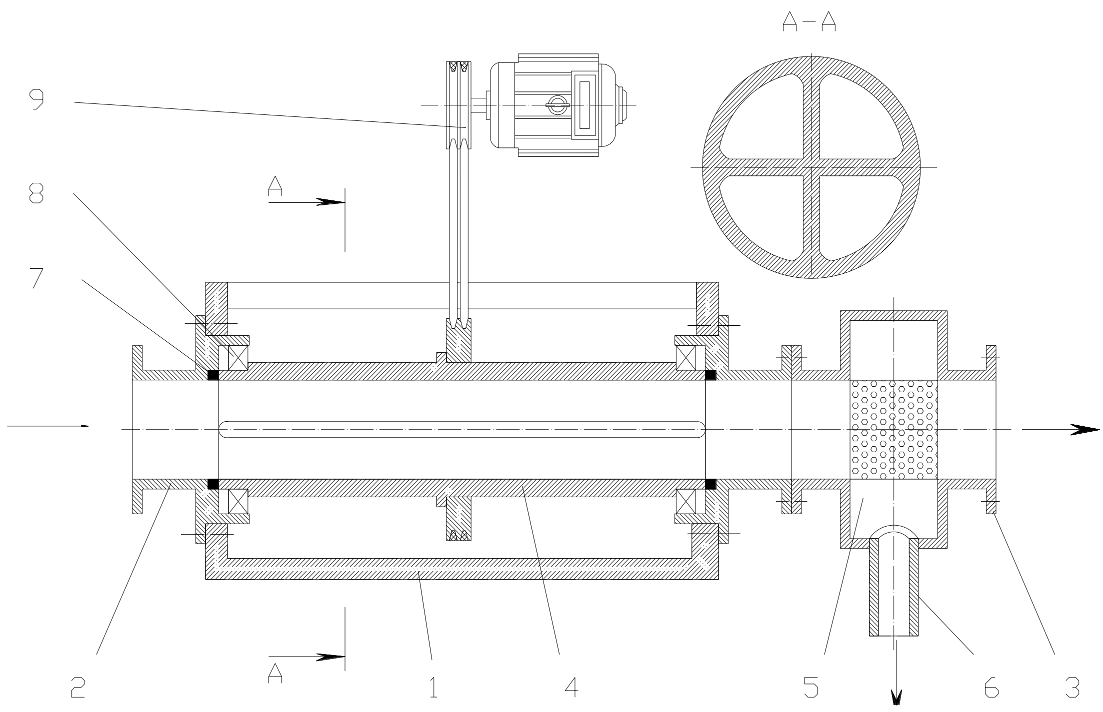

Fig. 1. Construction of a hydrocyclone:
1 – body; *2* – inlet flange; *3* – outlet flange; *4* – turbine; *5* – receiver-filter; *6* – nozzle; *7* – end seals; *8* – bearings; *9* – drive

intensifying the dehydration process by providing the flow with rotational motion. The cyclone works continuously. Oil enters the turbine 4 through the inlet flange 2, where it immediately enters the turbine 4. A centrifugal force is created in the turbine, which is hundreds of times greater than the force of weight, which leads to the movement of heavier particles of the emulsion to the walls of the turbine and the heterogeneous system is separated, creating in the central core from the light emulsion fraction. The created ring of heavy particles (water), moving with the flow, enters the receiver filter 5, after which it is diverted to the water preparation system through the nozzle 6. The dehydrated oil flow moves in the direction of the outlet flange 3.

The analysis of the technological process of dehydration of oil emulsions with the help of hydrocyclones shows that the determining factor for calculating the parameters of the machine is the radial component of the speed of movement of the emulsion particles.

To calculate the speed of movement of particles in the field of centrifugal forces, the same scientific principles are used as in the process of sedimentation under the influence of gravity, replacing the force of gravity with centrifugal force or their ratio [4]. This assumption does not take into account the change in the value of the centrifugal force when the particle moves from the center to the periphery of the flow, which, in turn, will significantly affect the trajectory of the heavy particle. Accurate determination of the particle movement trajectory will allow you to clearly determine the parameters of the dehydrator, namely the dependence of the geometric parameters of the machine on the frequency of rotation of the rotor, consumption and rheological properties of the emulsion.

Let's consider the movement of a particle of water moving in an untwisted emulsion flow (Fig. 2). Let's decompose the flow speed into two components: rotational ω_n and linear. Let's conditionally place the share of water in the plane $V_П$ YOZ and let's decompose its movement into speed components V_x, V_y, V_z:

$$V_y = \omega x, \tag{1}$$

$$V_z = V_{\Pi} . \qquad (2)$$

The value of the velocity component can be determined by integrating the differential equation of motion of a free material point, which takes into account the balance of all forces acting on the water fraction: V_x

$$F_i + F_c + R = 0 , \qquad (3)$$

where:
F_i is the force of inertia;
F_c - centrifugal force;
R - the reaction of the environment.

The Archimedean force and the force of weight, which act on the particle, are incomparably small compared to the centrifugal force and the reaction forces of the movement. Hence, the projections of the forces on the axis acting on the particle consist of the centrifugal force and reactions to its action, the inertial force and the reaction of the medium:

$$F_i = m\frac{d^2x}{dt^2} ; \qquad (4)$$

$$F_c = m\omega_{\Pi}^2 x ; \qquad (5)$$

$$R = \frac{\xi\rho_o S}{2}\left(\frac{dx}{dt}\right)^2 , \qquad (6)$$

where is the mass of the particle; - dimensionless coefficient of resistance of the medium, for the turbulent mode of motion; ρ_o - oil density; $\xi = 0,44$, $\rho = 797 - 862 \, {}^{\kappa g}\!/\!_{m^3}$ S - cross-sectional area of the particle (for a spherical particle).

The differential equation of motion of a material point for the case of movement of a particle of water under the influence of centrifugal force has the form:

$$m\omega_{\Pi}^2 x - m\frac{d^2y}{dt^2} - \frac{\xi\rho_o S}{2}\left(\frac{dx}{dt}\right)^2 = 0 ; \qquad (7)$$

The time of movement of the particle to the periphery of the rotor and the flow rate determine the length of the turbine, where the dehydration process should end. The movement

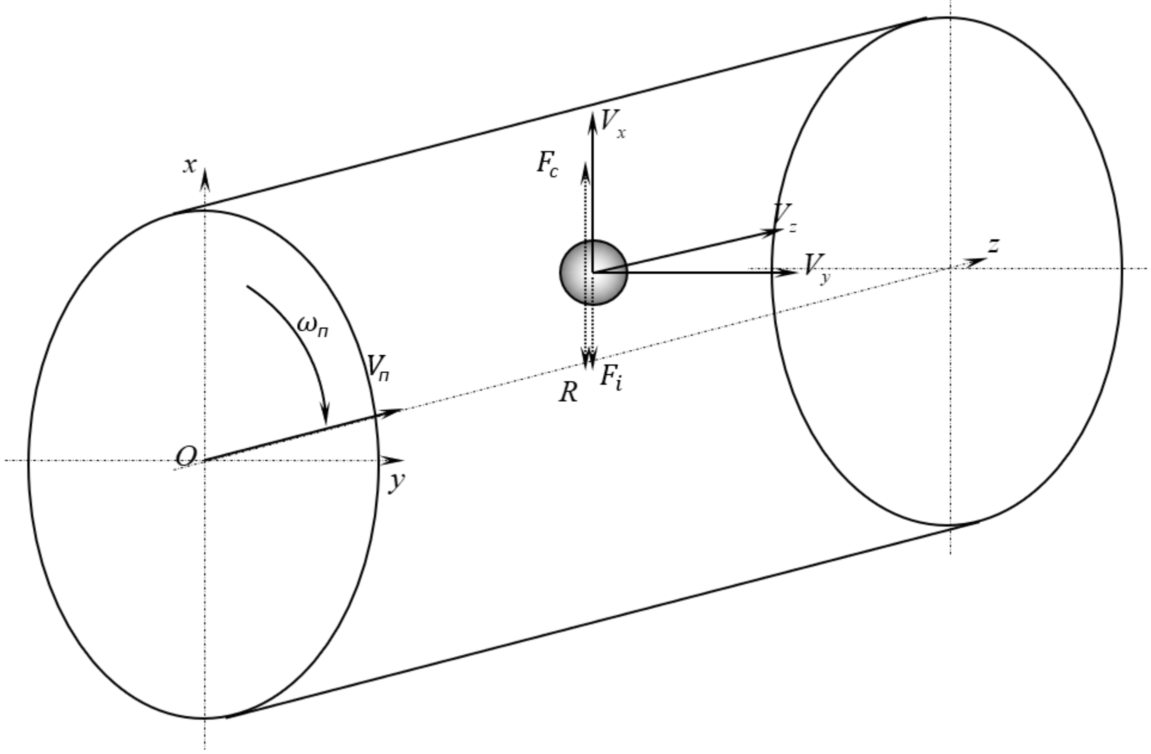

Fig. 2. Calculation diagram of the movement of the water fraction in the oil flow

ISSN(online)2709-6149. Mining, constructional, road and melioration machines, 101, 2023, 29-35

time and the length of the trajectory of the particles located near the center of the turbine will be longer compared to other particles. Therefore, the solution of the obtained equation must be considered for the conditions of the particle located near the center of the rotor. The initial conditions can be the speed values and coordinates of the particle that is as close as possible to the center of the turbine. Accordingly, the initial conditions , . When solving by a numerical method, it is possible to obtain the dependence of the change in the coordinate and velocity of an elementary particle on time under different conditions of dehydration (Fig. 3).

As can be seen from the graphs, with an increase in the speed of rotation of the turbine, the speed of the particle and the intensity of the coordinate change will also increase, which will make it possible to reduce the length of the cyclocyclone turbine. Reducing the size of the particle leads to a decrease in the speed of the particle and a slowdown in the change of the coordinate, which should also be taken into account when calculating the length of the turbine. It should be noted the low value of particle velocity in the central part of the turbine, which significantly prolongs the dehydration process. To reduce the impact of this phenomenon, it is possible to locate the rod in the central zone, which will allow the process to be intensified by giving the particles a greater initial value of the centrifugal force.

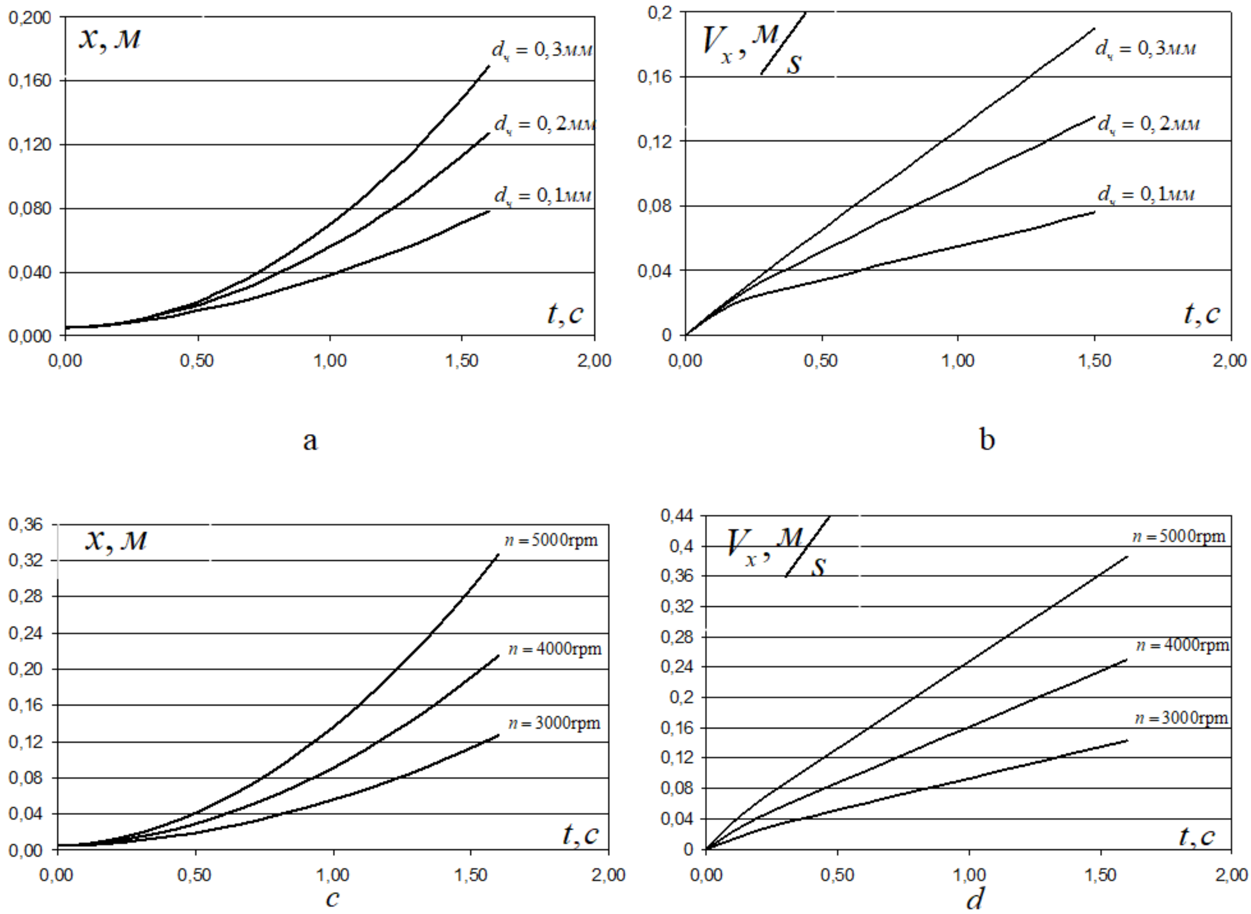

Fig. 3. Graphs of change of position (*a*, *b*) and velocities (*c*, *d*) fraction of water versus time for different sizes and speeds of rotation of the rotor

The process of dewatering oil in the above-mentioned way is accompanied by a constant change in the rheological properties of the emulsion as a result of separation into oil and water. In this way, the oil emulsion increases its density from the density of oil to the density of water. This process can be described by the density change rate gradient:

$$d\rho = \frac{(\rho_{H_2O} - \rho_o)}{R} dx, \qquad (8)$$

where:

ρ_{H_2O} - water density;

R - rotor radius.

Taking into account expression (8), the differential equation of motion of a particle of water under the influence of centrifugal force has the form:

$$m\omega_{\Pi}^2 x - m\frac{d^2 y}{dt^2} - \frac{\xi\left(\rho_o + \frac{(\rho_{H_2O} - \rho_o)}{R} x\right) S}{2}\left(\frac{dx}{dt}\right)^2 = 0 \qquad (9)$$

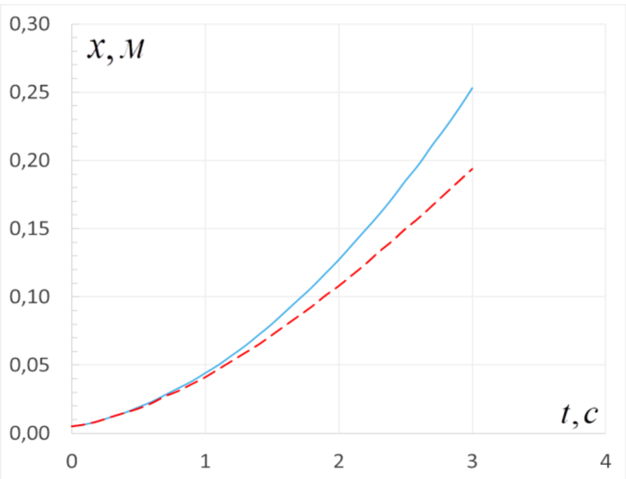

Fig. 4. The graph of the change in the position of the water fraction over time, taking into account the radial change of the rheological properties (---- - taking into account the change; ——— without taking into account the change):

$$n = 5000 rpm; d = 0,0001 m$$

CONCLUSIONS

The above calculations are valid for the deposition of a single particle and for dispersed systems with a small concentration of suspended particles, that is, in the case when the deposition of particles does not cause their interaction: collision, movements of one particle following another. With a high concentration of settling particles, their mutual influence must be taken into account. Deposition of particles in an environment with a high concentration of particles is characterized by phenomena that increase or slow down the rate of deposition. For example, the collision of particles can be accompanied by their agglomeration, which increases the rate of deposition; the movement of one particle after another also increases the rate of deposition; the collision of settling particles determines the action of additional frictional forces that slow down sedimentation. To take into account the described phenomena, it is necessary to take into account the change in the properties of the medium in the direction of the movement of the particle.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this study, including financial, personal, authorship, or any other, that could affect the study and its results presented in this article.

Financing

The study was conducted without financial support.

Data availability

The manuscript has no associated data.

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Визначення параметрів гідроциклону для обробки нафтової емульсії з примусовим обертанням потоку з врахуванням зміни реологічних властивостей

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Анотація. Об'єктом досліджень є процес зневоднення нафтових емульсій шляхом використання гідроциклону з примусовим обертанням потоку з врахуванням реологічних властивостей.

Проблема, що вирішується в роботі, пов'язана з видобутком, первинною підготовкою та транспортуванням нафт. Процес видобутку нафт супроводжується насиченням продукту водою, солями, механічними частками та легкими фракціями, що потребує первинної підготовки нафти шляхом багатостадійної, іноді довготривалої низькопродуктивної переробки з метою сепарації вищевказаних компонентів. Вміст води для деяких родовищ, особливо морських, складає 80%, що робить процес зневоднення нафти особливо важливим для підготвким нафти до транспортування. Серед відомих способів зневодення нафтових емульсій, таких як, відстоювання, термічна обробка, хімічна обробка, елетродегідрація та центрифугування, саме останнє дозволяє суттєво вплинути на процеси сепарації. Сутність процесу центрифугування, полягає у збільшенні обертальної швидкості руху часток дисперсної фази шляхом заміни природної сили ваги потужнішою відцентровою силою. Густина води й механічних домішок вище щільності нафти, і частки під дією відцентрової сили притискаються до стінки і, коагулюючи, видаляються через розділювач потоків.

В ході роботі визначено основні закономірності процесу центрифугування, а саме швидкість осідання частки води від реологічних параметрів емульсії та кінематичних характеристик гідроціклону з примусовим обертанням потоку. Встановлено, що залежність осідання частки води нафтової емульсії об'єму є степеневою функцією другого порядку, а швидкість лінійною. Осідання частки води має прямолінійну залежність від розміру частки. Швидкість Встановлена швидкість осідання часток води нафтової емульсії дозволяє розрахувати довжину турбіні в залежності від необхідної продуктивності, швидкості обертання та реологічних властивостей.

Розроблені теоретичні положення процесу зневоднення нафтових емульсій шляхом використання гідроциклону з примусовим обертанням потоку з врахуванням реологічних властивостей дозволяють проектувати машини даного типу для різних умов видобутку нафти.

Ключові слова: гідроциклон, емульсія, зневоднення, швидкість осідання, нафта.