Determination of oil-water emulsions separation efficiency in the separator with a vortex flow

I N Madyshev¹,*, A V Dmitriev² and Dang Suan Vin²

¹Kazan National Research Technological University, 68, Karl Marx str., Kazan, 420015, Russia
²Kazan State Power Engineering University, 51, Krasnoselskaya str., Kazan, 420066, Russia

*jeremiada@gmail.com

Abstract. This paper deals with the study of oil-water emulsions separation processes in the separators with a vortex flow. The authors developed a new design of separator, consisting of П-shaped elements and, when the liquid moves between these elements, the centrifugal force appears, leading to the layering of oil-water emulsion. The paper includes the numerical studies on the flow structure determination, conducted by means of software package ANSYS Fluent, and allowing us to evaluate the design of separators to achieve the high separation efficiency. It was found that an increase in the actual flow rate, and, as a consequence, the Reynolds number, as well as the height of device lead to an increase in the emulsion separation efficiency. At the same time, the oil concentration at the device outlet can reach 99.9%. The developed device allows to increase significantly the throughput capacity of apparatuses for the oil-water emulsions separation, widely used in the oil-and-gas extraction industry.

1. Introduction

One of the most important tasks, set for the oil-and-gas extraction industry, is to increase the depth of field based oil treatment. Currently, the inefficient devices, such as sedimentary basins, gravity separators, oil separators, hydraulic cyclones are used in the process layouts for the oil purification from water [1-3].

The most effective method to solve the problem of increasing the throughput capacity of apparatuses for the oil treatment is to intensify the processes of oil-water emulsions breaking in small devices. However, the used methods of emulsions centrifugation and the separation by means of membranes or electric fields imply the complicated design and sufficiently high energy costs [4-7].

2. Description of the device and its operation

The authors believe that in order to solve the problem of increasing the efficiency and capacity of apparatuses for the oil treatment, the device [8], containing a number of П-shaped separators, located with a convex surface towards the inlet nozzle for the oil-water emulsion, should be used. П-shaped separators in each subsequent row are located between the separators in each previous row (figure 1). When the oil-water emulsion moves between the elements of device, the centrifugal force appears, leading to the formation of circulation motion zones, within which the emulsion layering takes place.
The separated oil by gravity is removed from the device through the holes, executed within the bottom area. The use of several separation stages allows to increase the overall deposition efficiency of lighter emulsion fraction.

![Image](output_of_the_light_phase)

**Figure 1.** The principle of operation of proposed device for the oil-water emulsions separation.

### 3. Description of the study and its results

When developing the designs of proposed separators for the emulsions separation, an important task is to choose the most rational design and operating parameters, providing the high separation efficiency. In this regard, the numerical studies were conducted by means of software package ANSYS Fluent. The multiphase flow of emulsion “water (H₂O) - oil products (fuel-oil residue) (C₁₉H₃₀)” was studied at given values of density and viscosity $\rho_{\text{H₂O}} = 998.2 \text{ kg/m}^3$, $\mu_{\text{H₂O}} = 0.001003 \text{ Pa}\cdot\text{s}$, $\rho_{\text{C₁₉H₃₀}} = 960 \text{ kg/m}^3$, $\mu_{\text{C₁₉H₃₀}} = 0.048 \text{ Pa}\cdot\text{s}$. The multiphase Eulerian-Eulerian model “Volume of Fluid (VoF)” with the number of phases equal to two was used for the calculation. The volume ratio values of water and oil products were 0.7 and 0.3, respectively. In the course of calculations, the standard $k-\varepsilon$ turbulence model was used. The calculation was non-stationary with a time step equal to 0.02. The number of space steps within the time step was equal to 20.

The boundary conditions were the following: there was an average rate, normal towards the boundary $v$, within two inlet areas (inlet rate value) and within two outlet areas (free outlet) the values of rate vectors in the neighboring element matched with the value and direction in the previous cell; at all remaining boundaries the “wall” condition was set.

The studies were conducted with the width of П-shaped separators equal to $b = 20 \text{ mm}$, the length of the board was $h₁ = 10 \text{ mm}$, the gap between the two rows of separators was $h = 5.5 \text{ mm}$, and the diameter of holes for the outlet of emulsion light phase was $2.25 \text{ mm}$. In the course of studies the height of device $H$ was changed within the range of 10-30 mm as well as the average rate of emulsion within the narrowest section of device was changed within the range of 1-2 m/s. The analysis of flow structure in the proposed device for the emulsions separation shows that at high inlet flow rates, the uniform mixing of emulsion with formation of vortex flows is observed. The center of these vortex flows is located near the flange of П-shaped separator (figure 2). At the same time, almost symmetrical, uniform and stable circulation motion zones are formed, at the outlet of which the oil concentration is equal to 98.9% and 99.9% at average emulsion flow rates within the narrowest section of device equal to 1 and 2 m/s, respectively. It should be noted that the low emulsion separation efficiency at low rates (up to 0.5 m/s) due to insufficient inertia of flow was revealed in the course of previous numerical studies [9, 10].
Figure 2. The distribution of oil concentration in the separation device with a height $H = 30$ mm at the actual emulsion flow rate $W_h = 1$ m/s (a) and 2 m/s (b), respectively.

The results of studies show that an increase in the actual flow rate, and, as a consequence, the Reynolds number, as well as the height of device lead, as a rule, to an increase in the emulsion separation efficiency. Thus, for example, with an increase in the height of device from 10 up to 30 mm, an increase in the emulsion separation efficiency on average by 50.55% is observed (figure 3). When the Reynolds number is equal to 611 and the height of device is equal to 20 and 30 mm, the emulsion separation efficiency is equal to 0.923 and 0.999, respectively. The Reynolds number was determined by the formula:

$$\text{Re}_h = \frac{W_h \cdot h}{\nu_L},$$

where $W_h$ – actual rate of emulsion flow, m/s; $h$ – gap between two rows of separators, m; $\nu_L$ – coefficient of kinematic viscosity of emulsion, m$^2$/s.

Figure 3. The dependency of emulsion separation efficiency on the Reynolds number at different height of device $H$, mm: 1 – 10; 2 – 15; 3 – 20; 4 – 30.
The graph in figure 4 shows that an increase in the actual flow rate from 1.8 to 2 m/s at a height of device equal to 20 and 30 mm leads to an increase in the emulsion separation efficiency on average by 4.57% that allows to achieve the average efficiency value equal to 96.1%.

4. Conclusion
The conducted numerical studies show that in order to improve the capacity and efficiency of emulsion separation in the proposed device with a vortex flow, when developing the design, an engineer should choose the maximum height of device (up to 50 mm) and the actual emulsion flow rate within the narrowest section of device within the range of 2-2.5 m/s.

Thus, the use of proposed separators for the oil-water emulsions separation in the oil-and-gas extraction industry will significantly increase the throughput capacity of cleaning devices while maintaining sufficiently high separation efficiency.

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