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Influence of the separation elements' shape on the process of water-oil emulsion demulsification in the pipe

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Influence of the separation elements` shape on the process of water-oil emulsion demulsification in the pipe

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Abstract. In order to intensify the demulsification of water-oil emulsions, various types of separation elements for the settling tanks are proposed, namely, the corrugated plates with different orientation of corrugations, located at an angle of 45°, 135° and the cross-corrugated plates. The experimental studies of water-oil emulsion demulsification by means of a laboratory unit, using the developed separation elements were conducted. The conducted studies showed that the use of various separation elements inside the settling tanks allows intensifying the process of water-oil emulsion demulsification. The separation elements, considered in this paper, allow the performance of demulsification process with minimum 62% efficiency at the average rate of emulsion movement of more than 0.04 m/s. In the course of studies, it was found that the most effective of the considered separation elements are the corrugated plates with an orientation of corrugations, located at an angle of 45°, allowing the process of water-oil emulsion demulsification with an average efficiency of 80.1% at the movement rate within the range of 0.04–0.053 m/s. It is also shown that for the various separation elements, there are the most effective ranges of emulsion rates, at which the maximum values of demulsification efficiency are achieved.

1. Introduction

One of the most important tasks for oil treatment facilities is to improve the quality of oil-water emulsion separation. The relevance of this task is caused by the fact that the oil fields are exploited and the water concentration in the extracted oil increases, while the oil concentration decreases accordingly. Currently, when producing the oil, the concentration of stratum water can reach up to 80–90% [1–3].

The most well-known methods of water-oil emulsion separation are the following: settling, filtration, centrifugation, heat treatment, in-line demulsification, etc. The choice of a particular method depends on the following factors: thermal parameters of oil and water (specific weight, dynamic viscosity, etc.), the concentration of water-oil emulsion components, required efficiency of emulsion separation, etc. [4–9].

It should be noted that in the course of exploitation of oil fields, the parameters of water-oil emulsions may change, for example, due to the changing of original stratum conditions. In this regard, almost all oil treatment facilities have a multi-stage scheme for the purification of water-oil emulsions, the complex of which creates conditions that allow adapting to the changing of physical and chemical properties of the oil, as well as to the component composition. As a rule, the first stage of purification is the settling tank, in which the process of water-oil emulsion separation is based on the difference in water and oil densities. The advantages of settling tanks are the following: operation simplicity, large deposition surface, high reliability of equipment, increased cost-effectiveness since there is no need for periodical replacement of expensive filter elements or the use of demulsifiers, and high operation efficiency [10–14]. The main disadvantages of settling tanks are the following: bulkiness, inability to provide a stable hydraulic regime due to the change in the density of water-oil emulsion flow along the cross-section of apparatus, which is caused by the change of temperature, phase concentration and other parameters, as well as a relatively low rate of water-oil emulsion separation: when the movement rate of emulsions increases, the separation efficiency decreases due to the flow turbulence [15–18].

Therefore, an important task for the petroleum refining industry sector is to increase the efficiency and to speed up the processes of water-oil emulsion separation in settling tanks, since the subsequent stages of purification, including the use of demulsifiers and other methods, are the most expensive from an economical point of view. One of the most promising methods to increase the efficiency and to speed up the processes of water-oil emulsion separation in settling tanks is the use of various separation elements inside them, which allow to speed up the break of film that envelops the oil particles or water drops [19].

2. Purpose of research

The purpose of this research paper is to study the impact of various forms of separation elements by experimental method on the process of water-oil emulsion demulsification. In the course of study, the following types of separation elements were considered: corrugated plates with different orientation of corrugations, located at different angles of 45° or 135° and cross-corrugated plates. For the experimental modeling of water-oil emulsion demulsification process, using the separation elements, the laboratory unit was assembled, which includes the emulsion treatment vessel *1*, the cylindrical settling tank *2*, into which various types of separation elements were inserted: corrugated plates with different orientation of corrugations, located at an angle of 45° or 135° and cross-corrugated plates, pump *3*, a vessel for the sampler *4*, liquid filter *5* and shut-off valve on the emulsion supply line *6* (figure 1).

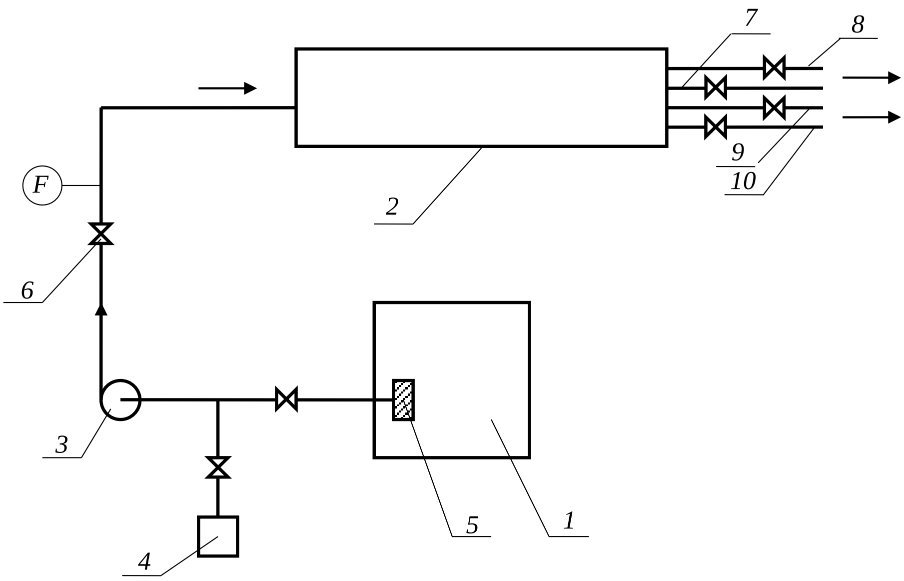

Figure 1. The experimental unit: *1* – vessel with original emulsion; *2* – cylindrical settling tank; *3* – pump; *4* – vessel for the sampler; *5* – liquid filter; *6* – shut-off valves on the emulsion supply line; *7* – the first line for the output of light phase; *8* – the second line for the output of light phase; *9* – the first line for the output of heavy phase; *10* – the second line for the output of heavy phase.

The process of water-oil emulsion demulsification in the laboratory unit can be described as follows: the treated water-oil emulsion was fed to the vessel *1*, after that to the cylindrical settling tank *2* by means of pump *3*; as the emulsion moved into the settling tank, a small part of it was fed to the sampling vessel *4* in order to record the value of oil and water concentration in the water-oil emulsion; the emulsion flow movement along different parts of laboratory unit was provided by opening and closing the shut-off valves *6*; the lines for output of light and heavy phases were arranged at the outlet of the cylindrical settling tank. It should be noted that the light phase was sampled from the first line of output *7* and the second line of output *8*, while the heavy phase was sampled from lines *9* and *10*.

In the course of experimental study, the following values were taken as constant: ambient temperature t_0 = 20ºC, water density ρ_{water} = 998.2 kg/m^3 and oil density ρ_{oil} = 880 kg/m^3, dynamic viscosities of water μ_{water} = 0.001004 Pa·s and oil μ_{oil} = 0.0198 Pa·s.

The efficiency of water-oil emulsion demulsification in the pipe was determined by the following formula [20]:

$$E = \frac{\overline{x_D} - \overline{x_F}}{1 - \overline{x_F}}, \quad (1)$$

where $\overline{x_D}$ – mass fraction of oil in the light phase, kg/ kg; $\overline{x_F}$ – mass fraction of oil in the original mixture, kg/kg.

3. Results and discussion

The graphical results of conducted studies are shown in figures 2–4. The use of various separation elements in a round pipe allows intensifying the process of water-oil emulsion demulsification. When the emulsion is in the direct contact with the surface of separation elements, the stratification effect for the oil components from water increases, due to the violation of the integrity of emulsion structure (the film, which covers the oil particles and water drops are broken) and relatively weak vortices near the curving outward, curving inward and other parts of separation elements that increases the probability of coalescence of water and oil drops.

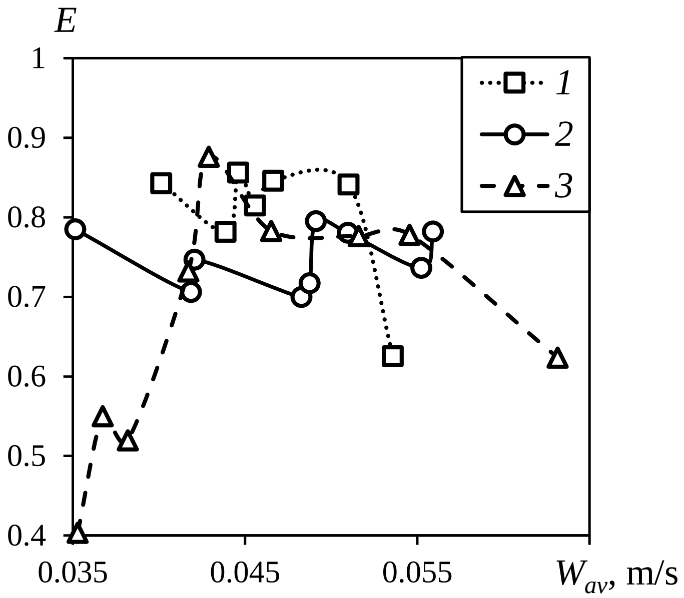

Figure 2. The dependency of change in the efficiency of water-oil emulsion demulsification on its average rate in a cylindrical settling tank with various separation elements: *1* – corrugated plates, with an orientation of corrugations at an angle of 45º, *2* – corrugated plates, with an orientation of corrugations at an angle of 135º, *3* – cross-corrugated plates.

The efficiency of water-oil emulsion demulsification, when using the corrugated plates with different orientation of corrugations, located at an angle of 45°,135° and the cross-corrugated plates, was on average equal to 74.1%. In the course of studies, it was also found that for the various separation elements, there are certain rate ranges W_{av}, at which the maximum values of water-oil emulsion demulsification efficiency are achieved. Thus, for the corrugated plates with different orientation of corrugations, located at an angle of 45°, the most optimal range is 0.04–0.05 m/s. while for the corrugated plates, located at an angle of 135° – 0.05–0.055 m/s and for the cross-corrugated plates – 0.04–0.055 m/s. This is due to the fact that the occurrence of different vortex forces depends not only on the water-oil emulsion rate but also on the shape of separation elements. Therefore, at the same rate, but when using different types of separation elements, different processes can be carried out – additional mixing of water-oil emulsion or coalescence of water and oil drops (figure 2).

According to the results of the study, the highest values of oil removal from the pipe are achieved when it is sampled from the outlet line, which is executed in the device at the highest elevation. When sampling the oil from the line of output *7* (figure 1) and using the corrugated plates with different orientation of corrugations, located at an angle of 45°, 135° and the cross-corrugated plates, its mass fraction in the light phase on average was equal to 89.4% (figure 3).

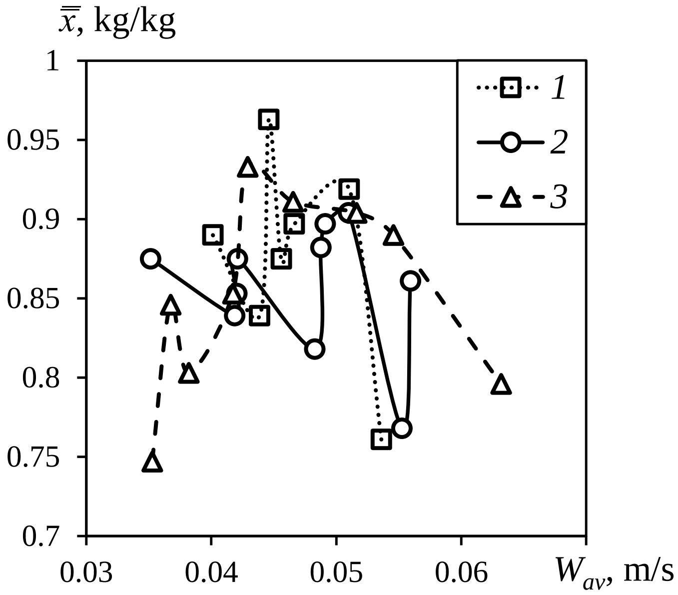

Figure 3. The dependency of oil mass fraction in the light phase, sampled from the first line of output, on the average flow rate when there are various separation elements: *1* – corrugated plates, with an orientation of corrugations at an angle of 45º, *2* – corrugated plates, with an orientation of corrugations at an angle of 135º, *3* – cross-corrugated plates.

When sampling the oil from the line of output *8* (figure 1) and using various separation elements, its mass fraction in the light phase on average was equal to 49.1% (figure 4). The obtained results also show that the required, correct length of pipe was chosen for the oil floating to the emulsion surface inside the pipe, which was separated from the water-oil emulsion when moving along the separation elements by the emulsion.

The efficiency of demulsification in the pipe when using the corrugated plates with different orientation of corrugations, located at different angles of 45° ,135° and the cross-corrugated plates, was on average equal to 80.1, 74.9 and 67.2%, respectively. At the same time, the greatest impact of changes in the average rate of water-oil emulsion in the pipe on the efficiency of its demulsification was recorded when using the cross-corrugated plates, due to a more complex profile of them in comparison with the corrugated plates, located at different angles in the pipe: at an average rate within the range of 0.035–0.039, 0.04–0.054 and 0.055–0.063 m/s, the demulsification efficiency was on average equal to 49.1, 78.9 and 63.1%, respectively. It should be noted that when the rate is less than 0.039 m/s, the low efficiency is caused by the fact that the water-oil emulsion only envelops the cross-corrugated plates, but there is no intensive separation of two phases. When the rate is within the range of 0.04–0.054 m/s, there is an optimal number of vortices, since the emulsion flows around the cross-corrugated surfaces, thereby achieving maximum efficiency values. When the rate is more than 0.055 m/s, the demulsification efficiency decreases due to a large number of vortex points and a greater force than for the rates within the range of 0.05–0.054 m/s, resulting in mixing of two phases (figure 2).

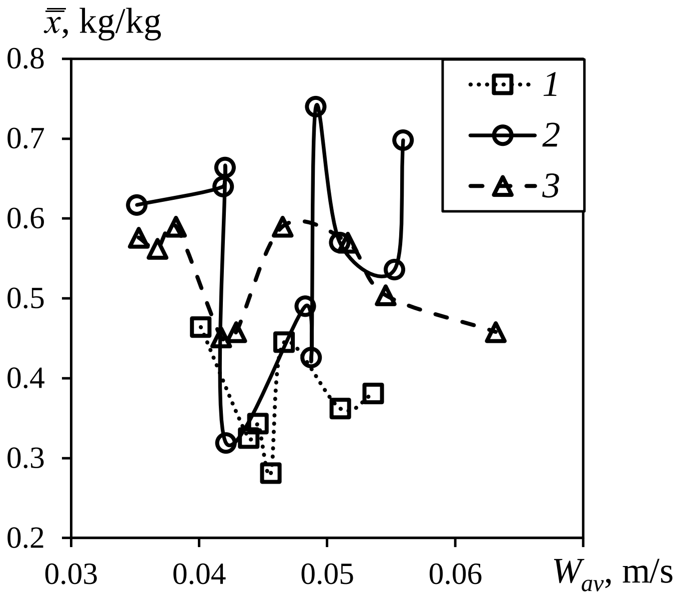

Figure 4. The dependency of oil mass fraction in the light phase, sampled from the second line of output, on the average flow rate when there are various separation elements: *1* – corrugated plates, with an orientation of corrugations at an angle of 45º, *2* – corrugated plates, with an orientation of corrugations at an angle of 135º, *3* – cross-corrugated plates.

When using the corrugated plates with different orientation of corrugations, located at an angle of 45°, 135° and the cross-corrugated plates, the oil mass fraction in the light phase was on average equal to 87.2, 95.2 and 85.3%, respectively. The maximum values of oil in the light phase, sampled from the first line of output *7* (figure 1), when using the corrugated plates with different orientation of corrugations, located at an angle of 45°, 135° and the cross-corrugated plates were recorded at the following rates: 0.044–0.051, 0.042–0.051 and 0.042–0.052 m/s, respectively (figure 3).

When using the corrugated plates with different orientations of corrugations, located at an angle of 45°, 135° and the cross-corrugated plates, the oil mass fraction in the light phase was on average equal to 37.1, 57.1 and 52.8%, respectively. The maximum values of oil in the light phase, sampled from the first line of output *8* (figure 1), when using the corrugated plates with different orientation of corrugations, located at an angle of 45°, 135° and the cross-corrugated plates were recorded at the following rates: 0.047–0.053, 0.049–0.056 and 0.046–0.054 m/s, respectively (figure 4).

4. Conclusions

The conducted studies showed that the use of various separation elements inside the settling tanks allows intensifying the process of water-oil emulsion demulsification. The separation elements, considered in this paper, namely, the corrugated plates with different orientation of corrugations, located at an angle of 45°, 135° and the cross-corrugated plates, allow a performance of demulsification process with minimum 62% efficiency at the average rate of emulsion movement of more than 0.04 m/s. In the course of studies, it was found that the most effective of the considered separation elements are the corrugated plates, located in the apparatus at an angle of 45°, allowing the process of water-oil emulsion demulsification with an average efficiency of 80.1% at the movement rate within the range of 0.04–0.053 m/s. It was also found that for the various separation elements, there are the most effective ranges of emulsion rates, at which the maximum values of water-oil emulsion demulsification efficiency are achieved: for the corrugated plates with different orientation of corrugations, located at an angle of 45°, 135° and for the cross-corrugated plates, these ranges correspond to the rates of 0.04–0.05, 0.05–0.055 and 0.04–0.055 m/s, respectively. The developed separation elements are of practical significance for the petroleum industry since the demulsification process of water-oil emulsion in most of the used settling tanks is ten times slower. Thus, the developed separation elements allow us to speed up the process of demulsification of water-oil emulsions significantly.

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