Advances in Raw Material Industries for Sustainable Development Goals

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Separation of water-oil emulsions in device with enlarged throughflow capacity

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ABSTRACT: The growth of production capacities of industrial enterprises leads to an increase in emission concentration of pollutants and requires the use of separators. This scientific paper includes the research of separation of emulsions with similar densities. The emulsions with similar properties are separated very slowly, so it is necessary to use special inserts to accelerate the separation process. The authors have chosen inserts with corrugated baffles, located at an angle of 45°, inserts with corrugated baffles, located at an angle of 135°, as well as inserts with cross-corrugated baffles. As a result of experimental research, it was found that with an increase in the emulsion rate inside of apparatus, the separation efficiency decreases, upon the condition that all the studied inserts are installed. When the concentration of hydrocarbons in the original mixture is less than 25%, it is most appropriate to use inserts with corrugated baffles, located at an angle of 45°.

1 INTRODUCTION

In recent years, the separation of oil and water was considered as one of the main problems all around the world due to an increased production of industrial oil-containing wastewaters. Nowadays, the separation of oil and water is still considered as a critical technical problem due to a complex composition and a high content of oily hydrocarbons in wastewaters. The traditional separation methods have low efficiency, high cost, and other types of pollution take place when these methods are implemented (Jiang et al., 2019, Li et al., 2020, Patterson, 1985).

The separators are usually the first stage between the oil source (for ex. oil field well) and oil process pipeline. When being transported inside the pipeline, the crude oil, by-produced water and gas move in a complex multiphase mode, and a finely dispersed emulsion usually creates a number of difficulties. The gas phase can be quite easily separated from the liquid flow; emulsions are usually stable and more difficult to be separated. As a rule, emulsions of "water in oil" type are very common for the oil production (Chen et al., 2009, Harpura et al., 1997, Sadeghi et al., 2013, Wang et al., 2012, Wang et al., 2016). They are mainly formed due to availability of amphiphilic hydrocarbons in the crude oil, such as asphaltenes, resins, and acids. Moreover, some chemical additives or solid particles, used inside of production piping network, contribute to the formation of stable emulsion. The stability of oil emulsified systems is highly dependent on the crude oil composition. Due to a wide range of compounds in the crude oil, the mathematical modeling of separation processes often gives significant errors, that`s why some problems can be solved only by conducting experimental studies. When producing the crude oil, the emulsions are mostly separated by gravity in vertical or horizontal apparatuses. Since the difference in the density of emulsion components is small, the apparatuses are usually designed with very large dimensions (Berman & Tamir, 2003, Cambiella et al., 2006, Sadeghi et al., 2011, Yang, 2007). Thus, the development, study and application of new apparatuses for the separation of stable emulsions are critical tasks.

In most cases, the choice of a particular type of design is based on a technical and economic analysis and takes into account local conditions, for example, the vertical settling tanks are used at low ground water level. Also, the choice of design is significantly affected by throughput capacity. The vertical, horizontal and radial settling tanks are used at the following throughput capacity of sewage treatment plants: not more than 10000, 15000-20000 and from 20000 m^3/day, respectively. As of today, one of the most promising ways to increase the efficiency of water-oil emulsion separation at the oil fields is to study different methods of improving the settling tanks. One of these methods is to study various inserts, to be installed inside the settling tanks, which have the form of webs, shields and other geometric bodies that increase the rate of water-oil emulsion stratification into components by changing the flow structure when moving along the obstacles. It should be noted that currently the flow rate of water-oil emulsions inside the settling tanks does not exceed a few millimeters per second, since at higher rates, the separation efficiency decreases significantly due to the phase mixing. Increasing the efficiency and separation rate of water-oil emulsions will reduce the costs for obtaining the finished petroleum products. Thus, the research and the use of new devices for the separation of stable emulsions is a relevant task. The purpose of this research paper is to study the increase in efficiency and separation rate of oil-water emulsions inside of continuously operating settling tanks.

2 RESEARCH PROBLEM

The purpose of this paper is to study the extraction of liquid oily hydrocarbon compounds from the emulsion. Two methods are usually used to separate the water-oil emulsions: reagent, using a demulsifies, and reagent-free.

The chemical method includes adding of various chemical reagents into the water to react with it. As a result of chemical reaction, the water is settled out as insoluble residues. This method helps to purify the emulsion by 95%. With a further increase in purification degree due to the use of chemical reagents, the water is contaminated with these chemical reagents. That is disadvantage of this method. The root of reagent-free method is to remove oil and oil products from the water by water settling out with the subsequent collection of oil by special devices: settling tanks, hydrocyclones, oil traps, etc. The main disadvantage of these apparatuses is a low degree of separation of water-oil emulsions (Diederen et al., 1998, Kou et al., 2019, Vanhoutte et al., 2011, Young et al., 1994, Zeng et al., 2016, Zhou et al., 2010,). In some cases, it is advisable to use the membranes for separation of water-oil emulsions (Babiker et al., 2019). However, if oil emulsions contain the components that can form a precipitate on the surfaces, then the membranes are very difficult to be used.

In order to improve the efficiency and to speed up the separation of water-oil emulsions, the authors developed several models of inserts, designed for continuously operating devices (settling tanks, separators), which are to be installed inside of these apparatuses. The research tasks also included the evaluation of possibility of developed inserts by experimental method to increase the efficiency of water-oil emulsion separation, to speed up its stratification, to determine the most effective rate ranges for each insert model, as well as to analyze the process of emulsion separation when it directly contacts with a certain model of insert.

3 RESEARCH METHODS

The experimental apparatus (Figure 1) consisted of separator (Dmitriev et al., 2019) with a cross-section of 60×60 mm with experimental inserts (Figure 2), valves for adjusting the flow rates of light and heavy phases, samplers for determining the concentration of hydrocarbon compounds after separation of emulsion, flowmeters LOUCHEN ZM FS300A G3/4" with an error of ±5% to calculate the rate of separated flows, tanks with a stirrer for remixing the separated emulsion and pump OASIS CRP 15/9 for feeding the emulsion into the separator.

In the course of experimental research, the following parameters were assumed to be constant: ambient temperature t_0 = 20°C; water density ρ_b = 998.2 kg/m^3; coefficient of water dynamic viscosity μ_b = 0.001003 kg/(m·s); density of oily hydrocarbon compounds ρ = 883 kg/m^3; coefficient of dynamic viscosity of hydrocarbon compounds μ_c = 0.0198 kg/(m·s). The concentration of oily hydrocarbons at the inlet of apparatus varied from 15% to 25%.

Various inserts were studied (Figure 2): *a* – insert with corrugated baffles, located at an angle of 45°; *b* – insert with corrugated baffles, located at an angle of 135°; *c* – insert with cross corrugated baffles. The depth of corrugations was equal to 10 mm. Along the entire length of plate, the holes were executed with a diameter of 1 mm and a uniform two-way pace of 3.5 mm. The holes were executed in such a way so that the sharp edges formed around them.

In the course of experimental research, the prepared emulsion was mixed in a tank by means of stirrer and the separated emulsion was fed into the apparatus by means of pump. When the tank was filled, the valves were opened to adjust the required flow rates of emulsion components, which were measured by flowmeters and after that, the emulsion, separated into

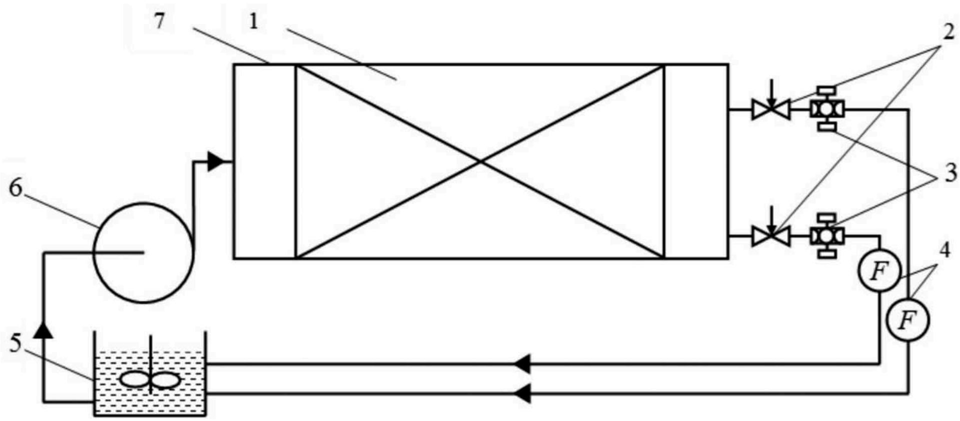

Figure 1. Experimental apparatus: 1 – experimental insert; 2 – control valves; 3 – samplers; 4 – flowmeters LOUCHEN ZM FS300A G3/4; 5 – tank for re-mixing of separated emulsion; 6 – pump OASIS CRP 15/9; 7 – experimental unit.

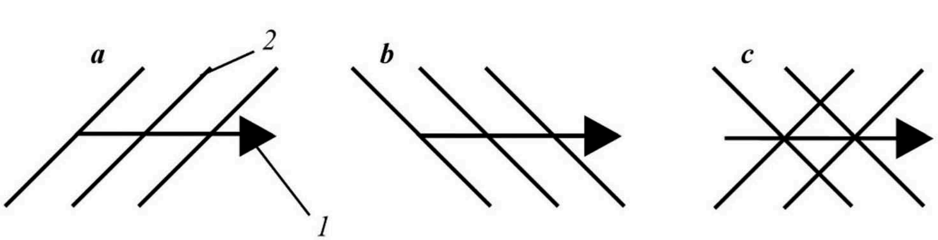

Figure 2. Models of experimental inserts: *a* – insert with corrugated baffles, located at an angle of 45°; *b* – insert with corrugated baffles, located at an angle of 135°; *c* – insert with cross corrugated baffles; *1* – direction of liquid flow movement inside of apparatus; *2* – corrugations.

light and heavy phases, was again fed into the tank. The concentration of hydrocarbon compounds at the outlet of apparatus was determined by the weight method. For this purpose, the sampling was carried out (at least 3 times, every 30 minutes) by samplers, on the scales R-25 with an error of ± 0.05.

4 RESULTS

The results of experimental research are shown graphically in Figures 3-5. With an increase in the emulsion flow rate, entering the experimental apparatus, the efficiency of extracting the liquid oily hydrocarbon compounds from the emulsion decreases. This is due to the fact that an increase in the input rate leads to an increase in the flow turbulence, resulting in a large number of vortex points that prevent the separation of oily hydrocarbon compounds from the emulsion. In order to intensify the processes of extraction of hydrocarbon compounds from the emulsion, it is necessary to use various inserts that are located inside of apparatus, contributing to the stratification of multiphase emulsion, i.e. arrangement of flow structure, contributing to the separation of compounds with different than the water has density.

In the course of research, it was found that the greatest efficiency of separator is achieved when using inserts with corrugated baffles, located at an angle of 45°. Such design increases the efficiency of stratification of oily compounds from the emulsion due to the orientation of corrugated surfaces, which shift the flow direction of lighter oily components against the water i.e. these components move upwards inside of apparatus, thereby intensifying the stratification process.

It should be noted that when the corrugated baffles are located at an angle of 135°, the emulsion separation efficiency is lower than when the baffles are located at an angle of 45°, because the orientation angle of baffles is almost coincident with the emulsion flow direction, that does not allow additionally affect the emulsion separation into different fractions. In the case of cross-corrugated baffles, an unordered emulsion flow is observed, resulting in two simultaneous processes throughout the whole insert, i.e. separation and mixing of mixture that leads to the lower efficiency.

The apparatuses without inserts provide the lowest efficiency of emulsion separation. This is caused by lack of elements inside of apparatus for intensification of separation of oily hydrocarbon compounds from the emulsion. The efficiency of extraction of liquid oily

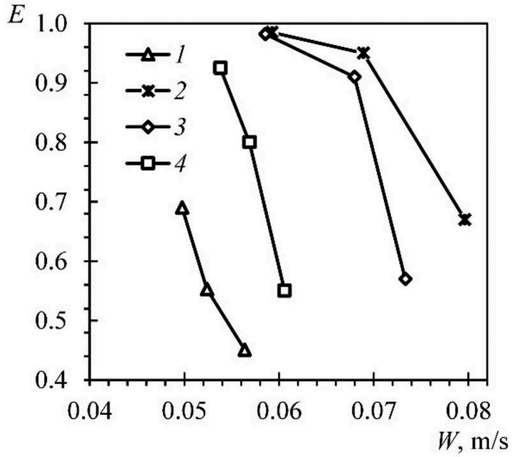

Figure 3. Dependency of liquid oily hydrocarbon compounds extraction efficiency from an emulsion, having 15 % concentration of hydrocarbons in the original mixture, on the input rate with various experimental inserts: *1* – without inserts; *2* – inserts with corrugated baffles, located at an angle of 45°; *3* – inserts with corrugated baffles, located at an angle of 135°; *4* – inserts with cross corrugated baffles.

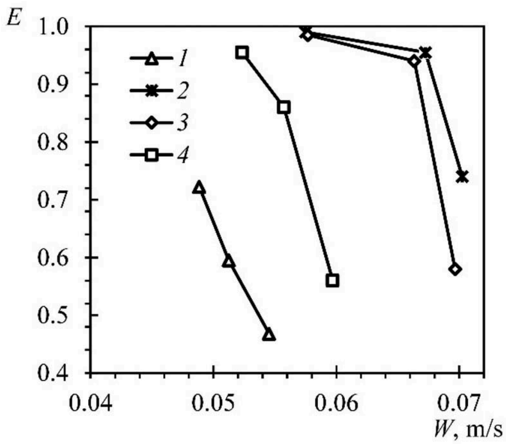

Figure 4. Dependency of liquid oily hydrocarbon compounds extraction efficiency from an emulsion, having 20% concentration of hydrocarbons in the original mixture, on the input rate with various experimental inserts: *1* – without inserts; *2* – inserts with corrugated baffles, located at an angle of 45°; *3* – inserts with corrugated baffles, located at an angle of 135°; *4* – inserts with cross corrugated baffles.

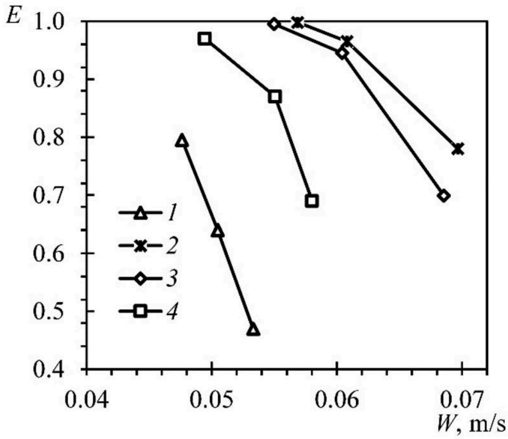

Figure 5. Dependency of liquid oily hydrocarbon compounds extraction efficiency from an emulsion, having 25% concentration of hydrocarbons in the original mixture, on the input rate with various experimental inserts: *1* – without inserts; *2* – inserts with corrugated baffles, located at an angle of 45°; *3* – inserts with corrugated baffles, located at an angle of 135°; *4* – inserts with cross corrugated baffles.

hydrocarbon compounds from the emulsion, with the concentration of them in original mixture of not more than 25%, on average is equal to 89.2, 84.5, 79.8 and 59.8% – when using the inserts with corrugated baffles, located at an angle of 45°, at an angle of 135°, inserts with cross corrugated baffles and without inserts, respectively, at the input rate within the range of 0.047–0.08 m/s.

5 DISCUSSION

When extracting the liquid oily compounds from the emulsion, with 15% concentration of them in the original mixture, the efficiency of apparatus on average was equal to 56.4, 86.8, 82.1 and 75.8% – when using the apparatus without inserts, with inserts with corrugated baffles, located at an angle of 45°, at an angle of 135°, and inserts with cross corrugated baffles, respectively. With an increase in the emulsion flow rate inside of apparatus, the separation efficiency decreased: when using the apparatus without inserts, an increase in the flow rate by 10% resulted in a decrease in efficiency by 52%; when using inserts with corrugated baffles, located at an angle of 45°, an increase in the flow rate by 25% decreased the separation efficiency by 32%; when using inserts with corrugated baffles, located at an angle of 135°, an increase in the flow rate by 20% decreased the separation efficiency by 42%, when using inserts with cross corrugated baffles, an increase in the flow rate by 11% decreased the separation efficiency by 41%. The highest efficiency of emulsion separation was equal to 69.1, 98.5, 98.2 and 92.5% – when using an apparatus without inserts, with inserts with corrugated baffles, located at an angle of 45°, at an angle of 135°, and inserts with cross corrugated baffles, respectively (Figure 3).

When extracting the liquid oily compounds from the emulsion, with 20% concentration of them in the original mixture, the efficiency of apparatus on average was equal to 59.5, 89.5, 83.5 and 79.2% – when using the apparatus without inserts, with inserts with corrugated baffles, located at an angle of 45°, at an angle of 135°, and inserts with cross corrugated baffles, respectively. An increase in the emulsion flow rate inside of apparatus on average by 0.006 m/s resulted in a decrease in the emulsion separation efficiency on average by 33.8%. An increase of liquid oily hydrocarbon compounds concentration in the emulsion from 15 to 20% led to an increase in the separation efficiency on average by 2.7% (Figure 4).

When extracting the liquid oily compounds from the emulsion, with 25% concentration of them in the original mixture, the efficiency of apparatus on average was equal to 63.5, 91.4, 87.9 and 84.3% – when using the apparatus without inserts, with inserts with corrugated baffles, located at an angle of 45°, at an angle of 135°, and inserts with cross corrugated baffles, respectively. An increase in the emulsion flow rate inside of apparatus on average by 0.008 m/s resulted in a decrease in the emulsion separation efficiency on average by 31.8%. The highest efficiency of emulsion separation was equal to 79.5, 99.8, 99.5 and 91.7% – when using the apparatus without inserts, with inserts with corrugated baffles, located at an angle of 45°, at an angle of 135°, and inserts with cross corrugated baffles, respectively. An increase of liquid oily hydrocarbon compounds concentration in the emulsion from 20 to 25% led to an increase in the separation efficiency on average by 4.9% (Figure 5).

6 CONCLUSIONS

The conducted research shows that in order to intensify the processes of extracting the liquid oily compounds from emulsions, various inserts, increasing the efficiency of apparatus at least by 17% in comparison with the apparatus without any inserts, shall be used. In the course of research, it was found that the most effective are the inserts with corrugated baffles, located at an angle of 45°, providing the most qualitative process of emulsions separation as a result of inhibition of liquid oily components by the surfaces of corrugations, moving upwards inside of apparatus due to a lower density than the water has. An obligatory requirement for achieving the highest possible efficiency of emulsion separation is to provide the relatively low flow rates. The highest efficiency of emulsions separation with a concentration of liquid oily hydrocarbon compounds in it within the range of 15-25% was on average equal to 73.1, 98.7, 99.1 and 94.3% – when using an apparatus without inserts, with inserts with corrugated baffles, located at an angle of 45°, at an angle of 135°, and inserts with cross corrugated baffles, respectively at minimum flow rates, which correspond to the following values: for an apparatus without inserts – 0.047 m/s, inserts with corrugated baffles, located at an angle of 45° – 0.057 m/s, inserts with corrugated baffles, located at an angle of 135° – 0.055 m/s, inserts with cross corrugated baffles – 0.049 m/s. The advantages of apparatus are high efficiency of liquid oily hydrocarbon compounds separation from emulsions, design simplicity, minimum capital and operating costs.

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