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ANALYSIS OF DROPLETS FORMATION PROCESS IN WATER-IN-OIL EMULSIONS

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Abstract

The paper analyses the influence of the conditions of oil-in-water emulsion formation in terms of the size of water droplets. Based on the similarity of water-in-oil emulsion formation processes in the laboratory and theoretical laws of droplet formation, the pipeline diameters of coalescing apparatus as well as the flow speed were determined, which ensured formation of droplets of optimal diameter for settling process.

Keywords: field based oil treatment; water-in-oil emulsion; droplets formation; physical-chemical properties; settling; water content.

1. Introduction

Dewatering and desalting of oil are the most important technological processes of oil treatment for transportation, which determine the quality (and therefore the cost) of the final product.

Development of the processes of oil treatment for various oil fields is heavily based on the laboratory results of water separation process investigation, in which the optimal conditions of water-in-oil emulsions breakup are determined. Physical modelling of water droplet dispersion is quite a challenging task, since it is necessary to take into account a number of factors, the main ones are hydrodynamic conditions in the coalescing apparatus, physical-chemical properties of water-in-oil emulsions, the completeness of coalescence processes [1].

For calculation of settling process, the key parameter affecting the rate of this process is droplet size of emulsion dispersed phase. The size of dispersed phase droplets, which are stable in pipeline, is typically calculated using empirical or semi-empirical calculation formulae [1–3].

One solution to the problem of determination of droplets formation process conditions in water-in-oil emulsion is modelling of the motion in pipeline with a stirrer, since the processes in a turbulent flow are essentially similar to the mixing processes used a paddle stirrer [1].

The aim of this work is to calculate and analyze the impact of water-in-oil emulsions formation conditions on the size of water droplets.

2. Experimental

The objects of this research were water-in-oil emulsions of Western Siberia oils, physical-chemical properties of which were determined by standard methods in the laboratory "Natural Fuel And Utilities Lab" of the Tomsk Polytechnic University (Tab. 1). The experimental investigations were performed according to the technique specified in the work [5].

When preparing the emulsions, the paddle stirrer mixing regimes were varied. This ensured different degree of water-in-oil emulsion dispersion. The process of droplets formation was studied using the microscope "LOMO" R2U42 with vertical lightening and 100 times amplification.

Table 1. Physical-chemical properties of oil samples

Property	Oil sample 1	Oil sample 2	Oil sample 3	Oil sample 4
Density at 20°C, kg/m^3	815	826	830	862
Kinematic viscosity				
at 20°C, m^2/s	2.75	3.70	4.72	11.44
at 50°C, m^2/s	1.29	2.30	2.36	4.86

In the work [1] the technique for pipeline diameter and emulsion flow rate selection is shown, according to which the maximum diameter of droplet formed under turbulent stirrer mixing is defined as:

$$d_{km} = 0{,}138 \cdot \sigma^{0.6} \cdot \rho^{0.6} \cdot n^{-1.2} \cdot d_m^{-0.8} \quad (1)$$

To define the diameter of droplet, formed in water-in-oil emulsion under mixing according to the equation (1), the calculation of surface tension was performed as follows [4]:

$$\sigma_0 = 10^{-2}\left(5\rho_{m277}^{293} - 1.5\right) \quad (2)$$

$$\sigma_T = \sigma_0 - 10^{-3}K(T - T_0); \; K = 0.07 \div 0.10 \quad (3)$$

At the present time to calculate droplet diameter in water-in-oil systems, a great number of various dependencies were suggested [1-2]. In the present work the following dependency was applied to calculate the maximum diameter of droplets, which are stable in turbulent fluid flow under pipeline conditions [1]:

$$d_k = 43.3 \cdot \frac{\sigma^{1,5}\left[1 + 0.7\left(\frac{\mu_d \cdot u}{\sigma}\right)^{0.7}\right]}{D^{0.1} \cdot u^{2.5} \cdot \rho_c \cdot \mu_c^{0.5}} \quad (4)$$

The condition of droplet formation process similarity is equality of droplet diameter in a stirrer (1) and a pipeline (4).

In summary, to calculate maximum diameter of pipeline droplets, which are resistant to breakup, the following dependencies were suggested, which reflect the influence of flow hydrodynamics on droplets formation process [1]:

$$d = AD\,\mathrm{Re}^m We^n, \quad (5)$$

where $\mathrm{Re} = \frac{uDp_c}{\mu_c}$; $We = \frac{u^2 D\rho_c}{\sigma}$.

3. Results and discussion

The main problem in modelling mass transfer processes of oil treatment is transfer of experimental data obtained in laboratory conditions to industrial facilities.

Various Western Siberia oil samples were experimentally studied by the authors of this research in terms of dynamics of oil dewatering process [5]. The results of these studies can be used for analysis and selection of oil dewatering process conditions and modelling of oil treatment technology [6–12]. To calculate the settling process, it is necessary to know the diameter of disperse phase droplet formed depending on technological conditions of the process.

Using the equation (1) the values of water droplet diameter in water-in-oil emulsion were defined with such varying parameters as the number of the stirrer rotations, temperature, water content and physical-chemical properties of oil (Tab. 2, Fig. 1).

It was shown that the stirring intensity influences much the water droplet size. Such parameters as temperature and density have much less influence on the water droplet size. The droplet diameter decreases with increase in water content in oil.

The calculation results of the size of droplets formed under various hydrodynamic conditions (equation (4)) are shown in Fig. 2, Tab. 2, and Tab. 3.

Table 2. Calculation of droplet diameter according to formula (1) with various number of rotations (water content in emulsion (W) is 30 wt.%)

Oil density, kg/m^3	Droplet diameter, μm			
	33 rps	25 rps	17 rps	8 rps
	Temperature 20ºC			
815	79.6	112.3	182.2	421.6
862	78.9	111.3	180.5	417.8
	Temperature 50ºC			
815	76.4	107.8	175.0	404.8
862	75.6	106.6	173.0	400.4

Table 3. The influence of the linear flow rate on the size of water droplets with various pipeline diameters (*D*) (the oil density is 815 kg/m^3; the temperature is 20 ºC; the water content is 10 wt.%)

	D=0.2 m		D=0.25 m		D=0.32 m		D=0.40 m	
u	dk	Re	dk	Re	dk	Re	dk	Re
0.5	651	25539	636	31923	621	40862	607	51078
0.6	414	30647	405	38308	395	49034	386	61293
0.7	283	35724	276	44693	270	57207	264	71509
0.8	203	40862	199	51077	194	65379	189	81724
0.9	152	45969	149	57462	145	73551	142	91940
1.0	117	51077	114	63847	112	81724	109	102155
1.1	93	56185	91	70232	88	89897	86	112371
1.2	75	61293	73	76617	71	98069	69	122587

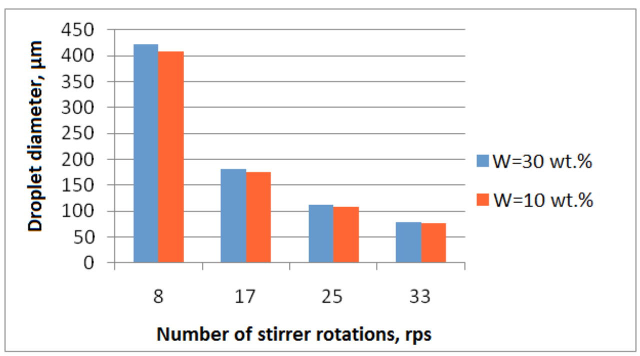

Fig. 1. Dependence of the average droplet diameter on the number of the stirrer rotations (the temperature is equal to 20ºC; the oil density is equal to 815 kg/m^3)

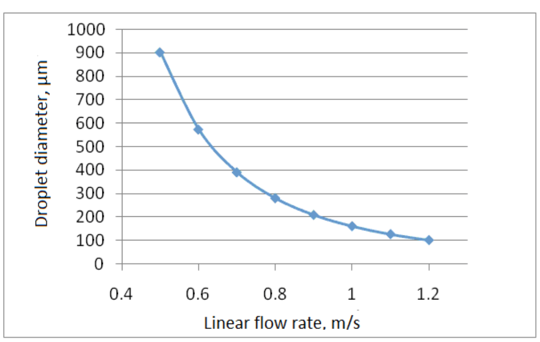

Fig. 2. Dependence of the droplet diameter on the linear flow rate (the temperature is 50ºC; the water content is 10 wt.%; the oil density is 815 kg/m^3)

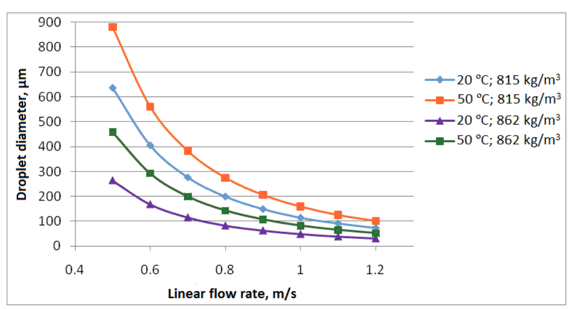

Fig. 3. Dependence of the droplet diameter on the linear flow rate, temperature, and oil density

Variations in size of droplets and values of the Reynolds number indicate a very strong influence of the linear flow rate, for example, when the flow rate varies from 0.5 to 1.2 m/s, the droplet diameter decreases almost nine fold (Tab. 3).

Fig. 3 shows the influence of the temperature and oil density on the size of droplets with various linear flow rates (the pipeline diameter is 0.25 m; the water content is 10 wt.%). With increase in temperature the rise in size of water droplets was observed, whereas with increase in oil density the diameters of water droplets decrease.

4. Conclusions

Using the technique based on the combination of the methods of physical and mathematical modelling, the optimal pipeline diameter and oil flow rate were determined to increase the effectiveness of droplet formation process.

The studies showed that the linear flow rate, pipeline diameter, physical-chemical properties of oil, and temperature have significant effect on the size of droplets.

In the considered range of parameters the hydrodynamic conditions of water droplets formation in the pipeline were determined. This ensured further effective settling process for Western Siberia oil samples. Thus, to form droplets with diameter equal to 182 μm at emulsion temperature equal to 20ºC (the oil density is 815 kg/m^3), the linear flow rate is 0.84 m/s for pipeline diameter 0.25 m. Therefore, the obtained results can be used for analysis and selection of process conditions for dewatering oil with different physical-chemical properties and modelling of oil treatment technology [6-12].

Symbols

ρ	*density of water-in-oil emulsion;*	μ_c	*dynamic viscosity of continuous phase;*
n	*rotation frequency;*	μ_d	*dynamic viscosity of dispersed phase;*
d_m	*diameter of stirrer turbine;*	A, m, n	*empirical coefficients;*
σ	*surface tension on the phase boundary;*	Re	*the Reynolds number;*
d_k	*maximum diameter of droplets;*	We	*the Weber number;*
u	*average fluid flow rate;*	ρ_c	*density of continuous phase;*
D	*pipeline diameter;*	μ_c	*viscosity of continuous phase.*

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