https://doi.org/10.18321/ectj797

Investigation of the Stability of Natural Water-Oil Emulsions Formed During the Extraction of High-Viscosity Petroleum of the Republic of Kazakhstan

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Article info

Received:
16 July 2018

Received in revised form:
10 September 2018

Accepted:
17 November 2018

Abstract

The Institute of Combustion Problems, in conjunction with the Kazan National Research Technological University, is carrying out research in the process of dehydration, desalination, transportation and primary processing of oil. In the course of the research, the methods used to determine the wetting and washing capacity, as well as the dispersion analysis of oil dispersed systems, were developed in the Institute. In order to change the viscosity and fractional composition of high-viscosity oils for improvement of further works, there is used an electrohydraulic action technology. It is established that the object of investigation is high-viscosity and heavy oil, is capable to form a stable commercial emulsion system in the collection system. The average size of water globules in oil is 9.8 μm and aggregate resistance is 89.3%. Experimental modeling of the universal emulsion of oil dispersion system is suitable for further study of the demulsification processes of water-oil emulsion, allowed to establish the regime conditions for dispersion and preparation of a stable water-oil emulsion. The aggregative stability (As, %) was estimated by centrifuging the water-oil emulsion under given different conditions for carrying out experimental studies, followed by the determination of the amount of water released from the oil in the process of separation of the system into two coexisting phases.

1. Introduction

The increase in the number of experimental and field works related to the testing and implementation of modern and new promising methods for increasing of oil recovery in productive formations leads to aggravation of problems in the preparation of heavy and highly viscous oils at many production facilities. Polymeric, micellar-polymeric or thermos-polymer flooding, acidic as well as acid and alkaline effect, etc., during processing of the bottom whole zones in order to improve the performance of injection wells or flooded production wells contributing to the formation of stable water-oil emulsions [1], the stability of which increases along the entire path of oil production – from gathering systems to central points for preparation of crude oil.

For the past few decades, there has been an increase in the share of extraction of high-viscosity oils of the coal-bearing horizon of the west regions of Kazakhstan. The current trend is significantly exacerbates the problem of training in the fields of oil, because carbon oils with associated reservoir waters are prone to the formation of particularly stable emulsion systems with a wide range of dispersed components, which are included in them as impurities (formation water, crystalline salts and mechanical impurities) [2]. At the same time a tendency to increase viscosity properties and aggregation stability of emulsion systems, oil is the reason for the high specific consumption of reagents demulsifiers having low surface activity at the interface and exhibiting insufficient effectiveness in destroying armoring shells in globules of water in oil, so that prepares oil fields has a low quality.

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The discrepancy of qualitative indicators of the prepared oil due to exploitation of old technological equipment, untimely development or impossibility to introduce modern technologies led to the formation of water emulsion systems in oil of secondary origin: stable emulsion intermediate layers, granary and slop oils, oil sludge and other oil production wastes. In this connection, it is most important and relevant to develop and implement such modern and advanced technologies based on combined techniques and methods (reagents, apparatus and equipment with new design features) an impact to the boundary adsorption layers between oil and formation water, which allow to exclude the possible formation and accumulation of various types of substandard products in collection system and preparation of well production, and for the first, where a high-viscosity and heavy crude hydrocarbons is extracted. Solving these pressing problems at a modern scientific and technical level, it is possible to ensure not only the normal operation and technological mode for preparation of high-viscosity oils, but additionally to involve a greater volume of the oil into commercial supplies, and also to solve the environmental problem in oil regions where the crude hydrocarbons is extracted and processed.

The scientists, researchers and field personnel are faced with an important goal – it's a development and implementation of the most effective new techniques, methods, methods and apparatus in dehydration and desalting processes, complicated by rheological and emulsion properties of oils. In accordance with this goal, the solution of actual field problems will improve the quality of the preparation of petroleum raw materials for further transportation, which would also meet the requirements for its primary and deep processing, and also eliminate or at least minimize the formation of secondary products – as the sources of losses and environmentally hazardous pollutions.

Over the past few decades, the extraction of high-viscosity oil of coal-measure unit in the western regions of Kazakhstan has increased. At the same time, the increasing tendency of viscosity properties and aggregative stability of oil emulsion systems is the reason for high specific consumption of demulsifying agents that having low surface activity at phase interphase boundary and exhibiting insufficient efficiency during destruction process of armor shells using water and oil globules, and as a result, prepared oil on site has poor quality.

It has been proved that [3–7] resinous asphaltene substances having high wetting and washing power, demonstrates high efficiency in the destruction of stable emulsion oils with a high content of natural emulsifiers and a high content of various mechanical impurities. Some researchers in order to enhance the demulsifying effectiveness of surfactants using various chemical, physical, mechanical, acoustic and combined influence methods on oil dispersed systems, as a supplement to the main process of their action. Physical stimulation techniques are based on the destruction of emulsions under conditions of intense heat and mass transfer, when the favorable conditions are created for deformation of structure of protective armor shells on the external surface of water globules. This is achieved by the influence of wave and electro-hydraulic methods of various physical nature and origin to the water-oil emulsion [8].

2. Experimental

When choosing the destruction methods for stable water-oil emulsions and follow-on development of the dehydration and desalting of highly viscosity oils, it is necessary to have some information on oil and stratal water to form the emulsion systems with high aggregate stability under certain conditions. In this case, an integral part of experimental researches is a prediction of "aging" time of natural emulsions, as well as establishment of the mode and preparation conditions for synthetic (model) water-emulsion oil dispersed systems with similar physicochemical and rheological properties in comparison with field emulsions. Only in this case, the models ensuring the composition consistency, invariance of properties and stability of synthetically prepared oil-water emulsions can be suitable for testing of demulsifying reagents, thermochemical and reagent-wave effects, as well as conducting of the researches on development of optimal operating conditions for the dehydration processes and desalting in the technology of preparation of high viscosity oils.

At the initial stage of the planned studies, a natural emulsion of high-viscosity and heavy oil was photomicrographed (Fig. 1) with the purpose of visual the structure of the oil dispersion system, belonging to the type of emulsion (water in oil or oil in water), the degree of dispersion and size of water globules in oil.

In this work, the aggregate stability (A_s, %) was estimated by a centrifugation of a water-oil emulsion under given various experimental conditions, followed by the determination of the amount of

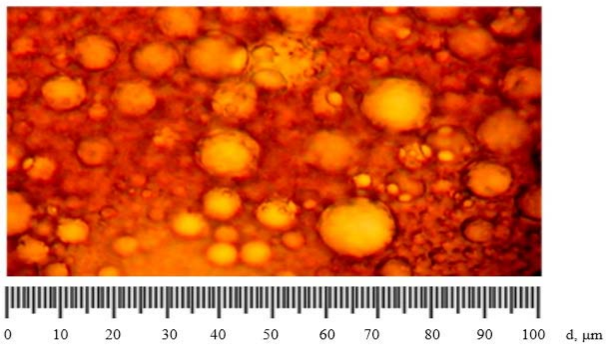

Fig. 1. Micrograph of a natural water-oil emulsion.

water released from the oil in the process of separation of the system into two coexisting phases [7]. The selection of centrifugation conditions was carried out in order to establish the most acceptable mode, which allows estimating reliable aggregative stability in the confidential interval ≈ 10 ÷ 90 %. The values of A_s were calculated by the formula:

$$A_s = \frac{W_0 - W}{W_0} \cdot 100, \%$$

where, W_0 – is the initial water content in the oil (the analyzed emulsion), ml; W – the amount of water released from oil during the process of emulsion centrifugation, ml.

The kinetic (sedimentation) stability of water-oil emulsions was determined according to the Stokes law and was estimated from the rate of sedimentation (υ_{sed}) under the action of gravity, i.e. gravitational force deposition of dispersed water droplets in oil. Sedimentation is related to the size of the water globules, which were determined with the help of a microscope.

$$\upsilon_{sed.} = \frac{2}{9} \cdot \frac{g \cdot r^2 \cdot (\rho_1 - \rho_2)}{\eta}, \ m/s$$

where, g – acceleration of gravity, 9.80665 m/s^2; r – radius of dispersed water globules in oil, µm; ρ_1 and ρ_2 – respectively, the relative density of the dispersed phase (water) and the dispersion medium (oil); η – kinematic viscosity of the dispersion medium, m^2/s.

The kinetic stability K_s of emulsion systems is inversely proportional to the rate of precipitation of dispersed globules of formation water in oil, and this dependence is expressed by the following equation:

$$K_s = 1/\upsilon_{sed}$$

A natural oil-water emulsion formed during the extraction of high-viscosity, and heavy oil from the Zhangurshi deposit was used to implement the planned program of studies of the stability of oil dispersed systems. Based on the results of studies of the physicochemical properties of petroleum raw materials in the Laboratory of petroleum chemistry of the "KSTU" (Kazan National Research Technological University) [8] it was established that an oil-water emulsion probe at the time of its recovery, had a water cut of 38.5% vol.

Determination of the aggregative stability of the industrial emulsion was carried out under three modes of centrifugation, depending on the rotational speed of the centrifuge rotor – 2000, 2500 and 3000 rpm in 5 min. It was found that under the influence of centrifugal force with a relatively small number of rotations of a 2000 rpm centrifuge, the emulsion was not practically divided into two coexisting phases – oil and formation water. Therefore, it is not possible to evaluate the stability of the emulsion system under such a centrifugation mode. With the increase in the number of revolutions of the centrifuge to 3000 rpm, the emulsion completely collapsed to such an extent that in the separated oil phase the residual water content determined by the Dean-Stark method left "traces". This fact testified the impossibility of conducting a correct assessment of the stability of the emulsion, because this indicator is almost zero. The most suitable mode was the following centrifugation conditions: the speed of rotation was 2500 rpm; room temperature (≈ 20 °C); centrifugation time – 5 min. Under such optimal conditions and initial water cut, 27.7% vol. the industrial emulsion after partially separated formation water during the day was characterized by numerical values of aggregative stability, and A_s = 89.3% and kinetic stability $K_s = 14.21 \cdot 10^6$ (m/s)$^{-1}$.

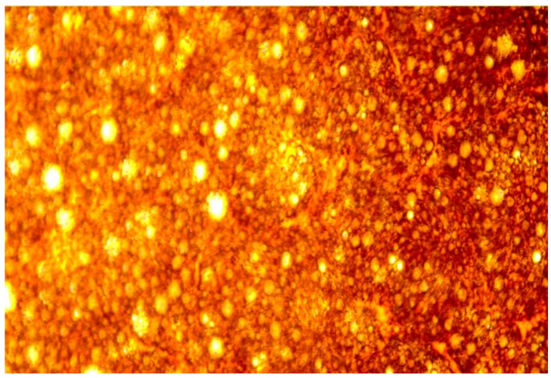

Fig. 2. Photomicrograph of the "old" of field water-oil emulsion during 1.5 months.

When free water is segregated during the day and was drained from a sample for 45 days of storage of the natural oil-water emulsion under static conditions, there is not occurred additional separation of stratal water from crude oil volume. This fact indicates a rather high stability of the emulsion is formed under field conditions. In addition, for current period of time, the "aging" of oil-water emulsion was noted, which was reflected at increasing of its stability. In order to fix this circumstance, foreseeing the manifestation possibility of this fact within ≈1.5 months from sampling moment, the studies on establishment of temporal dependence of natural field emulsion were conducted. For this reason the microphotograph of "old" emulsion was made (Fig. 2), which allowed to state that the structure of oil dispersed system was significantly transformed compared to the freshly sampled sample due to association of resinous-asphaltenic substances and redistribution of complex structural units polar in nature due to volume of the dispersion medium closer to oil-water interface. The tendency of resinous asphaltene substances to association and structuring was certainly accompanied by the emergence of a more powerful reservation (adsorption) layer on water globules, as evidenced by an increase in the aggregative stability of the emulsion during its "aging" (Fig. 3).

Experimental modeling of the universal emulsion oil dispersion system, suitable for further investigation of the process of demulsification of water-oil emulsion, was carried out under different conditions of dispersion of partially dehydrated oil with water cut of 27.7% vol. As the dispersed phase, commercial reservoir water was used, which was collected in the installation of preliminary dumping of water pre-drainage tank of the pre-dehydration oil drainage line.

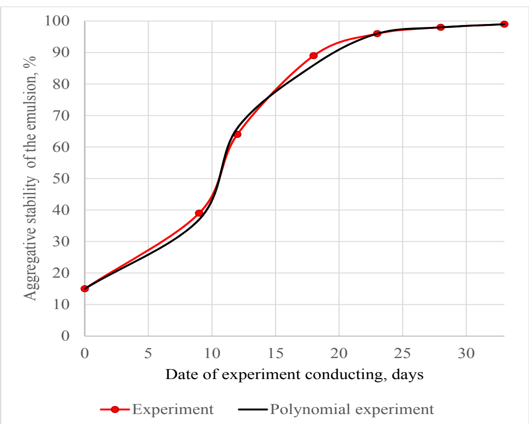

Fig. 3. Change dependence of emulsion stability through time.

Conditions for the formation of model emulsions: temperature – 20 °C; Water cut of the emulsion – 20, 25, 30, 35, 40%; Dispersion time – 1, 3, 5 min; The speed of the agitator of the disperser is 1000, 1500 rpm. Conditions for centrifugation in determining the aggregative stability: centrifugation time – 5 min; The speed of the centrifuge is 2500 vol/min; temperature – (≈ 20 °C). For calculation of kinetic stability, i.e. determining the time (s) of the water globule subsidence by 1 m, the average radius of the emulsified globules of the formation water in oil was estimated by microscopy. In Fig. 4 (Table 1, exp. No.5) and 5 (Table 1, exp. No.23), microphotographs of emerging water-oil emulsions are presented under various experimental modeling conditions.

The model emulsions shown even visually show the fundamental difference between the two water-oil emulsion systems in the dispersion and size of the water globules, as well as in the sphericity of the droplets of the dispersed phase or its absence, which makes it possible to draw a conclusion about the thickness of the emerging armor layer at the oil-water interface rigidity of emulsion preparation and indirectly to judge the stability of experimental models for destruction.

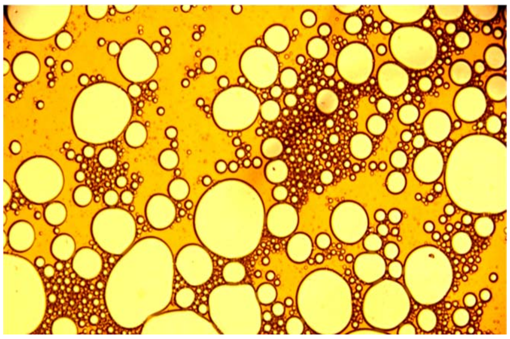

Fig. 4. Microphotograph of model water-oil emulsion (temperature – 20 °C, water cut of the emulsion – 40%, dispersion time – 1 min, number of revolutions of the stirring device (mixer) of the disperser – 1000 rpm).

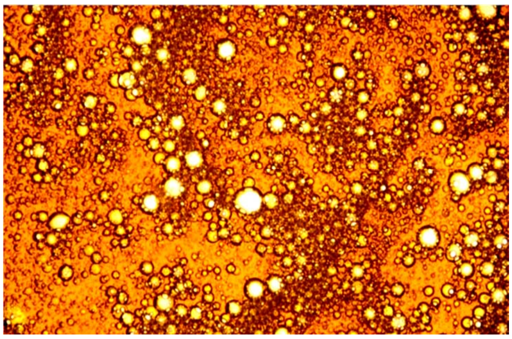

Fig. 5. Microphotograph of model water-oil emulsion (temperature – 20 °C, water cut of the emulsion – 30% by volume, dispersing time – 3 min, the speed of the agitator of the disperser is – 1500 rpm).

Table 1 shows the results of experimental simulation of emulsion systems under various conditions of their formation, which allowed us to establish parameters ensuring the obtaining of a model that is the closest in dispersion and stability in comparison with the natural commercial water-oil emulsion (sample No.2).

To establish the stability of conservation of a stable state in time that was obtained under equal conditions of the model emulsion, 5 parallel experiments were performed according to the experience of section 23 of Table 1. The results obtained are summarized in Table 2 and show that the identity of the emulsions is obvious.

Thus, the conditions for modeling the universal emulsion (Table 1, exp. No.23) are temperature – 20 °C; water cut of the emulsion – 30%; dispersion time – 3 min; The speed of the disperser agitator is 1500 rpm. In this case, the aggregative and kinetic stability of the commercial and model emulsions are identical. Consequently, the identified and accepted experimental modeling conditions will allow to obtain in future a universal water-oil emulsion, the properties and composition of which will be constant, and use it in subsequent experimental studies of the processes of dehydration and desalting of high-viscosity and heavy oil.

Table 1

The stability of the model oil-water emulsions

#	Experimental conditions				The average size of water globules (d), μm	Aggregative stability (A_s, %)	Kinetic (sedimentation) stability ($K_s = 1/\upsilon_{sed.} \cdot 10^6$)
	Temperature °C	Water cut vol. %	Time of dispergation, min	The speed of the disperser, rpm			
0	20	27.7	natural emulsion		10	89.3	14.21
1	20	20	1	1000	35	20.9	0.94
2	20	25	1	1000	37	19.5	0.84
3	20	30	1	1000	40	16.6	0.72
4	20	35	1	1000	42	12.5	0.65
5	20	40	1	1000	45	9.6	0.57
6	20	20	3	1000	18	50.5	3.56
7	20	25	3	1000	19	49.5	3.20
8	20	30	3	1000	20	48.7	2.88
9	20	35	3	1000	26	40.0	1.71
10	20	40	3	1000	29	34.0	3.17
11	20	20	5	1000	15	62.2	4.51
12	20	25	5	1000	17	59.5	3.99
13	20	30	5	1000	18	56.0	3.56
14	20	35	5	1000	21	53.3	2.68
15	20	40	5	1000	22	51.5	2.38
16	20	20	1	1500	25	42.2	1.85
17	20	25	1	1500	28	36.0	1.47
18	20	30	1	1500	30	29.5	1.28
19	20	35	1	1500	32	25.5	1.13
20	20	40	1	1500	33	23.0	1.06
21	20	20	3	1500	5	98.1	46.15
22	20	25	3	1500	6	96.0	32.05
23	20	30	3	1500	10	91.1	14.21
24	20	35	3	1500	10	86.5	11.54
25	20	40	3	1500	11	83.2	9.54
26	20	20	5	1500	2	100.0	228.46
27	20	25	5	1500	3	100.0	128.20
28	20	30	5	1500	5	98.0	46.15
29	20	35	5	1500	7	93.4	23.55
30	20	40	5	1500	10	90.1	11.54

Table 2
Experimental results of parallel experiments comparing the stability of a model water-oil emulsion (according to section 23 of Table 1)

№	Date of executing the experiment	Experimental conditions				The average size of water globules (d), μm	Aggregative stability (A_s, %)
		Temperature, °C	Water cut vol. %	Time of dispergation, min	The speed of the disperser, rpm		
0	4.03.2017	20	27.7	natural emulsion		9.8	89.3
1	14.03.2017	20	30	3	1500	9.1	89.4
2	16.03.2017	20	30	3	1500	9.0	89.2
3	18.03.2017	20	30	3	1500	8.9	89.1
4	21.03.2017	20	30	3	1500	9.2	89.5
5	24.03.2017	20	30	3	1500	9.1	89.4

Comparing the results of high-viscosity oil after initial water separation and oil-water emulsion is forming in collection system prior to initial water separation during production in collection system, it should be concluded that natural field emulsions of high-viscosity oils with formation water are very prone to "aging" during short time of storage. Such oil disperse systems are capable to increase the aggregative stability; therefore, they are completely unsuitable for experiments that planned for a long time – 2–3 years. Therefore, the preservation and maintaining of the properties and composition of emulsion should be consigned to conducting of the experimental modeling and development of preparation conditions of universal emulsion oil disperse system for further usage in studies oriented to high-viscosity oil demulsification processes that prepared for transportation and primary processing.

3. Conclusions

The results of the experiments showed that the research object – high-viscosity and heavy oil (sample No.1) that arrives before the preliminary discharge of formation water into the oil field of the Zhangurshi deposit in the Mangystau region in the form of an oil-water emulsion for preparation and further transportation through the oil pipeline, is capable of forming in the collection system a stable commercial emulsion system with averaged size of the globules of water in oil ≈ 9 μm and the aggregative stability of A_s = 89.3%.

Experimental modeling of the universal emulsion oil dispersion system (sample No.2), suitable for further study of the process of demulsification of water-oil emulsion, allowed establishing the regime conditions for dispersion and preparation of a stable water-oil emulsion in composition and dispersion, and stable in time.

Acknowledgments

Experimental research was carried out within the framework of the federal program "Research and development in priority areas for the development of the scientific and technological complex of Russia for 2014–2020" under the Agreement No. 14.577.21.0176, Unique identifier No. RFMEFI57715X0176 on "New physical and chemical technologies in the processes of collection, transportation, preparation and processing wells of high viscosity and heavy oils".

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