

## RESEARCH, DESIGN, CALCULATIONS, AND OPERATING EXPERIENCE

### PROCESSES AND EQUIPMENT FOR CHEMICAL AND OIL-GAS PRODUCTION

#### EXPERIENCE OF IMPLEMENTING AN INTENSIFYING DEVICE ON THE DEVELOPED MOBILE WELL PRODUCTION TREATMENT UNIT

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*The process of emulsion separation using an intensifying device tested on the developed mobile well production treatment unit was subjected to quantitative analysis followed by approbation. During tests, cassettes were mounted in the sump of the mobile unit with a distance of 5 mm (standard design) and 2.5 mm between the plates. Experiments were conducted with some variation: with the fluid entering the horizontal sump from the top and from the side, process temperature varying from 60 to 70°C, and with varying fresh water flow rates. It was found that the smaller distance between the plates ensures turbulent diffusion in the intensifying devices, leading to a more intensive oil treatment. It was also found that desalting processes proceed more intensively at 70°C than at 60°C and when fresh water flow rate is increased by 10 and 20%. A 30% increase in the flow rate of fresh water leads to an appreciable increase in the fraction of water in the treated drip oil, the desalting process deteriorates. The study showed that the use of intensifying devices with a distance of 2.5 mm between the plates leads to improved oil treatment: water cut decreased by 2–37% and the content of chloride salts decreased by 5–74% depending on the process.*

**Keywords:** oil treatment, crude oil, separator, oil sump, mobile treatment unit, intensifying device.

Instability of the oil treatment process at on-site facilities leads to deterioration in the quality of marketable products. Maintaining the required oil characteristics using accessible and economically sound thermal, physical and chemical methods at all stages of oil collection, transportation and treatment is one of the most important tasks for full production cycle oil companies [1, 2].

On the territory of TsDNG-7 of LUKOIL-Perm (Perm Krai), the crude oil produced is described as heavy (from 871 to 895 kg/m<sup>3</sup>), highly viscous (up to 87 mPa·sec at 20°C), paraffin-containing (up to 6%), highly resinous (more than 15%) and with an increased content of asphaltenes (6% or more). The water cut of crude oil, depending on the streams supplied to the oil treatment and pumping unit (OTPU), varies within 34–55% [3, 4]. The high viscosity of the emulsion (crude oil) interferes with the effective coalescence of dispersed phase droplets, and the high content of high molecular weight natural stabilizers (resins and asphaltenes) leads to the formation of strong armor shells on the globules of the dispersed phase (formation water), which greatly complicates the processes of coarsening and precipitation of fine drops of water [5–7]. In these conditions, the produced oil often does not answer the quality requirements of commercial oil. Therefore, it is important to study

TABLE 1. Initial Data for Calculating the Critical Diameter of Particles

| Parameter (at process temperature)                                      | Value  |
|---|--------|
| The flow rate of the emulsion through the gap between two plates, m/sec | 0.0047 |
| Distance between plates, m  | 0.0025 |
| Length of plates, m   | 0.8    |
| Dynamic viscosity of oil, mPa·sec                                       | 21.1   |
| Dynamic viscosity of water, mPa·sec                                     | 1      |
| Density of oil, kg/m <sup>3</sup>                                       | 905    |
| Density of mineralized water, kg/m <sup>3</sup>                         | 1180   |

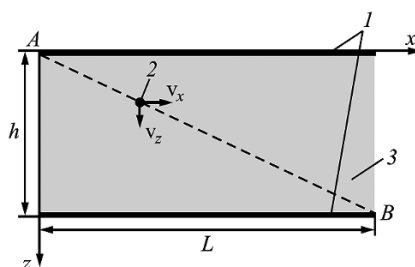


Fig. 1. Schematic of the process of precipitation of dispersed phase (mineralized water) in a dispersion medium (oil) in the inter-plate space of an intensifying device: 1) plate; 2) a particle of water; 3) oil.

the processes of dehydration and desalting of oil under the given treatment conditions and develop technical means for intensifying the process of emulsion separation.

The process of emulsion separation is based on the model of coagulation and precipitation of spherical water globules in oil. The determining factor in this case is the linear size (diameter) of the particles of the dispersed phase, which can be increased as a result of water globules joining together and thus enlarging. The most accessible, economically and technologically sound is the use of intensifying devices, based on the mechanisms of turbulent diffusion and coagulation of disperse systems [8]. Compared with the process of coalescence in the open volume of the dispersion medium, the efficiency of the process of emulsion breaking on the contact device is significantly increased [9].

Quantitative analysis and subsequent approbation of the process of emulsion separation using an intensifying device on the developed mobile well production treatment unit (MWPTU) were performed [10, 11], allowing to model the technological processes of emulsion separation without affecting the main production process.

**Formulation of the problem.** One of the reasons thorough dehydration and desalting of oil is impossible in case of complete destruction of the armor shells and using large volumes of washing fresh water is the small size of water globules suspended in the oil (no more than 1–10  $\mu\text{m}$ ). When the size of globules is so small, their collision with larger drops of washing fresh water and fusion with them are practically impossible, since small droplets are easily entrained by microflows of oil flowing around larger droplets as they move. Generally, small droplets come in contact with the large globules only when the trajectory of the small drops coincides with the line connecting the centers of the large and fine drops. Ultimately, in oil there are almost always extremely small drops of mineralized formation water with destroyed armor shells that did not participate in mass-exchange processes and did not settle on the bottom of the device in a technologically acceptable amount of time. However, as the distance from the location of the drop to the drainage water layer decreases (due to the use of special-purpose coalescers), highly dehydrated and desalted oil can be obtained without changing other process parameters.

TABLE 2. Research Results

| Fraction of particles, vol.% | Weighted average particle diameter, $\mu\text{m}$ |
|------------------------------|---|
| 3.9                          | 7   |
| 12.8                         | 27  |
| 28.4                         | 69  |
| 14.7                         | 122   |
| 10.0                         | 164   |
| 11.1                         | 219   |
| 11.3                         | 286   |
| 7.8                          | 338   |

The following assumptions were made in solving the problem: oil contains small particles of water, the particles of water are approximately spherical, the emulsion is premixed to a homogeneous state. The volume between the plates of the intensifying device (ID) with a length  $L$  located at a distance  $h$  from each other is used as a geometrical model of the process of precipitation of water globules in the emulsion.

Consider the case of free motion of a dispersed phase particle (without colliding with other particles) along a trajectory corresponding to the maximum path length between the plates (Fig. 1).

**Solution of the problem and the numerical experiment.** In analyzing the kinematics of a particle, we assume that the liquid system in the axial direction of the device moves practically in piston mode. The velocity components of the dispersed phase (mineralized water) particles in the dispersion medium (oil) in the  $zx$  plane can be represented in the form

$$dx/dt = v_x; \quad dz/dt = v_z, \quad (1)$$

where  $v_x, v_z$  are the projections of the velocity of the particle on the  $x$  and  $z$  axes, respectively;  $t$  is time.

When considering the system in the inter-plate space of the ID, a differential dependence can be obtained from Eq. (1):

$$dx/v_x = dz/v_z; \quad (2)$$

$$\frac{\delta^2(\rho_w - \rho_0)g}{18\mu\lambda} dx = v_x dz, \quad (3)$$

where  $\delta$  is the particle diameter;  $\rho_w, \rho_0$  are the densities of mineralized water and oil;  $\mu$  is the dynamic viscosity of the oil; and  $\lambda = 3(\mu_w + \mu_0)/(3\mu_w + 2\mu_0)$  is the correction factor [12].

Integrating Eq. (3) over the particle path connecting the points  $A(0; 0)$  and  $B(h; L)$ , we get

$$\frac{\delta^2(\rho_w - \rho_0)g}{18\mu\lambda} L = v_0 h, \quad (4)$$

from which the critical diameter of the particle is obtained:

$$\delta_{cr} = \sqrt{\frac{18\mu\lambda v_0 h}{(\rho_w - \rho_0)gL}}, \quad (5)$$

where  $\mu_w, \mu_0$  are the dynamic viscosities of the dispersed phase (water) and the dispersion medium (oil), respectively.

The geometric meaning of Eq. (5) is that all particles with a diameter  $\delta \geq \delta_{cr}$  passing through point  $B(h; L)$  will precipitate on the wall of the ID (see Fig. 1).

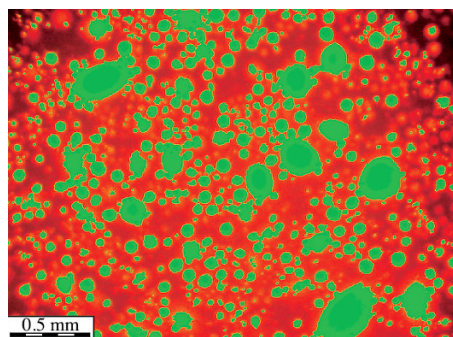


Fig. 2. Oil emulsion (microphotography).

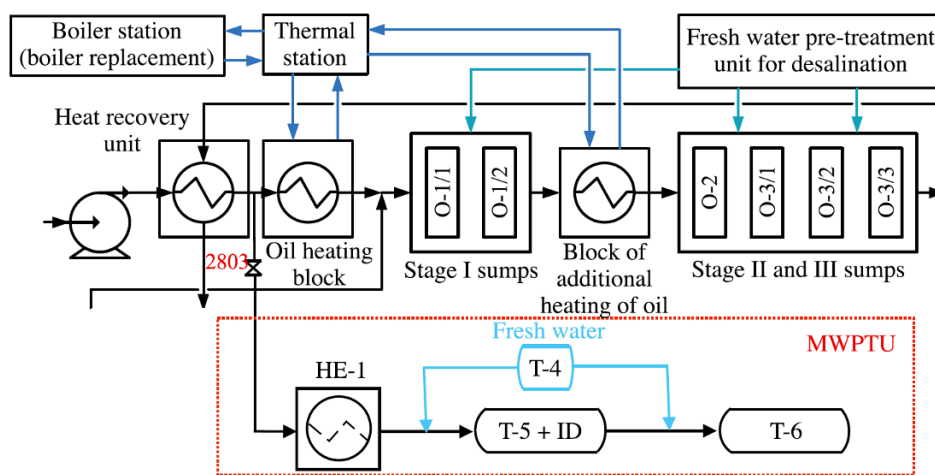


Fig. 3. MWPTU Setup design: HE-1 – heat exchanger; T-4 – fresh water supply tank; T-5 + ID – horizontal sump  $V = 1.6 \text{ m}^3$  with the intensifying device; T-6 – horizontal sump  $V = 1.6 \text{ m}^3$ .

Solving Eq. (5) for the initial data (Table 1) yields  $38 \mu\text{m}$  as the critical diameter of the particles of the disperse phase.

Investigations of the emulsion collected at the inlet of the stage I sump showed that 83.3% of the globules of mineralized water have a diameter greater than  $38 \mu\text{m}$  and can be removed from oil using the ID with a distance of 2.5 mm between plates (Fig. 2, Table 2), the estimated water cut of the emulsion in this case will be up to 0.5%.

**Approbation of results.** To confirm the results of the calculation, pilot tests were carried out on the OTPU of LUKOIL-PERM according to the following scheme (Fig. 3): the MWPTU was connected to the oil line coming from the RPS-2; drainage, dumping of oil, water and gas were output to the general sewerage network. The volumetric flow rate of oil through the unit was  $0.58 \text{ m}^3/\text{h}$ , which corresponded to the duration of the emulsion preparation process on the OTPU and the MWPTU.

The intensifying device installed in the horizontal sump of the MWPTU is a set of cassettes consisting of plates made of 12Kh18N10T grade steel supported on studs, the distance between the plates was varied by installing washers between them (Fig. 4).

The purpose of the pilot tests was to improve the quality of oil in accordance with GOST 51858-2002 by selecting the optimal technical characteristics of the ID (the distance between the plates) and the technological parameters of the process (heating temperature, flow rate of the fresh water for desalination, change of the direction from which the emulsion enters the sumps). Characteristics of the initial (operating) technological scheme of preparation were as follows: water cut at the inlet – up to 3%, at the outlet – up to 0.6%; the content of chloride salts at the inlet was 12500 mg/liter, at the outlet – up to 130 mg/liter, which corresponds to less than the highest quality of oil in terms of the content of chloride salts.

TABLE 3. Intensity of the Dehydration Process (Stage 1) When the Distance Between Plates is 2.5 and 5 mm

| Index           | Process intensity at a given temperature |            |            |                            |            |            |                         |            |            |                            |            |            |
|-----------------|--|------------|------------|----------------------------|------------|------------|-------------------------|------------|------------|----------------------------|------------|------------|
|                 | 60°C                                     |            |            |                            |            |            | 70°C                    |            |            |                            |            |            |
|                 | Entering T-5 from above                  |            |            | Entering T-5 from the side |            |            | Entering T-5 from above |            |            | Entering T-5 from the side |            |            |
|                 | $q + 10\%$                               | $q + 20\%$ | $q + 30\%$ | $q + 10\%$                 | $q + 20\%$ | $q + 30\%$ | $q + 10\%$              | $q + 20\%$ | $q + 30\%$ | $q + 10\%$                 | $q + 20\%$ | $q + 30\%$ |
| Water cut, %    | 9.5                                      | 31.6       | 11.8       | 13.0                       | 18.2       | 4.8        | 10.0                    | 37.5       | 2.1        | 18.8                       | 15.8       | 2.1        |
| Salt content, % | 43.3                                     | 69.1       | 14.5       | 59.9                       | 9.4        | 4.7        | 37.1                    | 74.4       | 36.8       | 31.7                       | 44.0       | 16.3       |

**Notes.** The values given in the table were determined using the equation  $K_i = (C_{\delta=5} - C_{\delta=2.5})/C_{\delta=2.5}$ , where  $C_{\delta=5}$  is the water fraction (%) / salt content (mg/liter) for a distance of 5 mm between plates;  $C_{\delta=2.5}$  is the water content (%) / salt content (mg/liter) for a distance of 2.5 mm between plates.

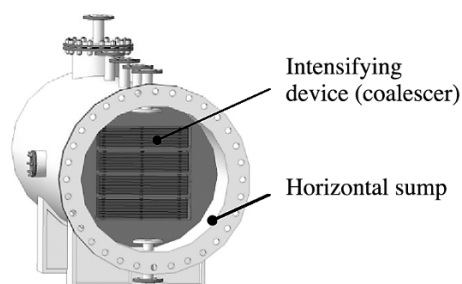


Fig. 4. Scheme of installation of the intensifying device.

Experience introducing intensifying devices in the oil sumps at the facilities of LUKOIL-PERM showed that the distance between the working elements should be at least 8 mm. To this day, no studies have been conducted to determine the optimal clearance. In this regard, cassettes with a plate separation distance of 5 mm (basic construction) were installed in the sump tank T-5 for testing (see Fig. 3). Studies were carried out varying the direction from which the fluid entered the horizontal sump (from above, from the side), the process temperature (60 and 70°C), and the flow rate ( $q$ ) of fresh water on the OTPU (increasing the flow rate by 10, 20, and 30% compared to the current operating regime). The flow rate  $q$  of fresh water supplied to the MWPTU (corresponding to the supply to the OTPU) was 21 liters/h.

Sampling was carried out to assess the effect of the gap between the plates (2.5 and 5 mm) on the quality of the treated oil. A total of 24 experiments were performed.

The distance between the centers of the drops of fresh and reservoir (mineralized) water in conditions of insufficient dispersion in the MWPTU is reduced when the distance between the plates inside the technological device T-5 is decreased. Thus, with the installation of coalescing cassettes with a distance of 2.5 mm between plates in the T-5 sump, the quality indicators (water cut and chloride content) are improved in comparison with the distance of 5 mm between plates (Table 3). At the same time, the water cut of oil after passing through the ID in the T-5 sump corresponded to the calculated value (Fig. 5), confirming accuracy of model (5). In addition, the positive values in Table 3 characterize a more thorough degree of oil preparation when the distance between the plates is smaller, which indicates the effectiveness of the process of precipitation of oil droplets in the small gap of the ID.

To increase the efficiency of the desalting process, it is necessary to estimate the degree of dispersion of fresh water droplets in fresh water supply devices, which is determined by the pressure drop in the disperser and the degree of dispersion of the supplied liquid.

Analysis of the results of laboratory studies of oil samples showed that the importance of the direction from which the product entered the sump T-5 decreased as the process temperature increased from 60 to 70°C and the distance between the plates increased from 2.5 to 5 mm (Table 4).

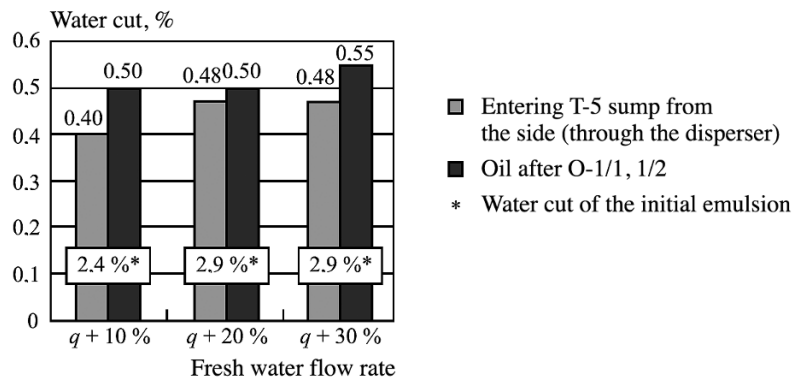


Fig. 5. Results of analysis of oil samples after stage I (heating temperature 70°C, distance between plates 2.5 mm).

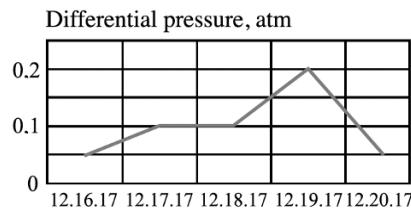


Fig. 6. Plot of the pressure difference between the inlet to the MWPTU and the outlet from the sump T-5 with the ID (2.5 mm distance between plates).

It was also found that when the process temperature is 70°C the direction from which the product enters the sump T-5 does not affect the parameters of the oil treatment process. Thus, according to the results of analysis of the technological regimes of operation of the MWPTU, it can be concluded that the dehydration processes (separation of droplet water – the fine dispersed phase, from oil – the dispersion medium) and desalting (reduction of the content of chloride salts in the treated product) depend to the greatest extent on the process temperature. At 70°C, desalination processes are more intense than at 60°C, while a 10% and 20% increase in fresh water flow rate makes it possible to further increase the intensity of the desalting process. However, with a 30% increase in the flow rate of fresh water, there is a marked increase in the fraction of drip water in the treated oil, the desalting process efficiency is reduced, which is confirmed by the results of analysis of oil samples after each stage of treatment.

In the course of the tests, the degree of blockage of the device was assessed in the case when the distance between plates was 2.5 mm by applying the dynamics of the change in pressure drop before and after the tank housing the plate cassettes (Fig. 6), and the cleanliness of the through-passages of the cassettes was estimated by visual inspection after the tests.

Over the test period of 5 days, there was no decrease in the throughput capacity of the cassettes with a 2.5 mm gap between the plates for inlet pressure of the MWPTU ranging from 3.6 to 4.7 atm. The throughput channels were free of large mechanical impurities and solid paraffins.

**Conclusion.** The calculations carried out based on Eqs. (1)–(5) are valid, practically valid and can be effectively used in the design of technical characteristics of ID for the destruction of emulsions. According to the results of experimental field research, it was confirmed that the use of ID with an inter-plate distance of 2.5 mm makes it possible to improve the degree of oil treatment in terms of the water cut by 2–37% and the content of chloride salts by 5–74%, depending on the technological process parameters. The tested technical means of intensifying dehydration and desalination of oil can be scaled to the production facility, allowing to optimize the capital and operating costs of oil treatment, to increase the stability of operation of the oil treatment and pumping unit in order to obtain marketable oil of the highest quality.

TABLE 4. Intensity of Dehydration and Desalting Processes

| Stage         | Index           | Process intensity determined by the distance between the plates |            |            |                            |            |            |                         |            |            |                            |            |            |
|---------------|-----------------|---|------------|------------|----------------------------|------------|------------|-------------------------|------------|------------|----------------------------|------------|------------|
|               |                 | 2.5 mm  |            |            |                            |            |            | 5 mm                    |            |            |                            |            |            |
|               |                 | Entering T-5 from above   |            |            | Entering T-5 from the side |            |            | Entering T-5 from above |            |            | Entering T-5 from the side |            |            |
|               |                 | $q + 10\%$  | $q + 20\%$ | $q + 30\%$ | $q + 10\%$                 | $q + 20\%$ | $q + 30\%$ | $q + 10\%$              | $q + 20\%$ | $q + 30\%$ | $q + 10\%$                 | $q + 20\%$ | $q + 30\%$ |
| Oil after T-5 | Water cut, %    | 5   | 19         | -11        | 44                         | 16         | 11         | 28                      | 14         | 2          | 37                         | 18         | 18         |
|               | Salt content, % | 52  | 21         | -4         | 33                         | 48         | 20         | 59                      | 17         | -40        | 62                         | 12         | -2         |
| Oil after T-6 | Water cut, %    | 6   | 6          | 0          | 0                          | 13         | 36         | 57                      | 21         | -17        | 36                         | 21         | 1          |
|               | Salt content, % | 13  | 15         | 6          | 9                          | 4          | 62         | 64                      | 21         | -41        | 108                        | 13         | -10        |

**Note.** The values given in the table were determined using the equation  $K_i = (C_{t=60} - C_{t=70})/C_{t=70}$ , where  $C_{t=70}$  is the water fraction (%) / salt content (mg/liter) at a process temperature of 70°C;  $C_{t=60}$  represents the same for 60°C.

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