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# STRUCTURAL ANALYSIS AND EXPERIMENTAL STUDY OF OIL EMULSION SEPARATION PROCESSES INVOLVING REAGENTS

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This study presents a structural analysis of the physical phenomena involved in the processes of oil emulsion separation. Various aspects of adsorption layer formation on droplet surfaces by asphaltene-resin compounds are discussed, along with models for calculating the mass and thickness of the layer. It is demonstrated that the formation of adsorption films on the surface of water droplets provides a significant resistance to their merging at collision, resulting in aggregatively stable emulsions. Emulsion separation occurs in subsequent stages following the destruction of these films using various reagents. The mechanism of adsorption film destruction involves the diffusive transfer of demulsifiers to the film surface, followed by their adsorption and penetration into the film's volume. Equations describing coalescence during the collision of a high-viscosity droplet with an ordinary one are proposed, and expressions for calculating droplet collision frequency are derived. Experimental studies on oil emulsion separation processes have been conducted. It is established that in the experimental study many physical phenomena (convective diffusion transfer, formation of intermediate layer, etc.) can be neglected, which significantly simplifies the description of the process. The description of the experimental process in the form of a model is based on the equations of convective diffusion transfer of water mass from the bulk of oil as a function of demulsifier flow rate and temperature. Comparison curves of experimental and calculated values are given to validate the model.

**Keywords**: oil emulsion, adsorption layer, coalescence, water, experiment, sedimentation, demulsifier, high-viscosity oil.

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## *Introduction*

Oil emulsions belong to multiphase systems characterized by all varieties of phenomena inherent to disperse systems. Classical features of disperse systems are as follows: aggregate state of phases, dispersity and size of particles, concentration of dispersed phase and the nature of interaction at the interface. Oil disperse systems, as a special class of these systems, combine simultaneously in one suspension (oil as a solid phase) liquid emulsions (water–oil), gas suspensions (gas–oil) and many other forms of their existence. In these systems, the first phase is distributed in the oil in the form of solid particles, water droplets, dissolved gas bubbles and their various combinations. A special place in oil is occupied by dissolved asphaltene-resin and paraffin substances, which play an important role in structure formation and filtration with inherent rheological properties [1–4]. Oil-structured disordered systems containing coagulation structures of crystals of high molecular weight paraffin and particles of asphaltene-resin substances forming a chain or, in an extreme case, a continuous grid (framework), acquire the ability to flow only after the destruction of this grid $\tau > \tau_0$ (where $\tau$ is the shear stress and $\tau_0$ is the yield strength), and small external stresses produce elastic deformation of the grid or framework.

In principle, heavy oils belong to aggregatively unstable systems, where continuous formation and destruction of structures as a result of coagulation, coalescence, aggregation, crushing and destruction are observed. Interaction of asphaltene particles is accompanied by creation of rather strong aggregates of coagulation nature and, first of all, doublets, triplets, due to Brownian diffusion motion of separate particles.

Under the action of shear flow, these structures break down into individual particles, and the equilibrium shifts towards the formation of individual particles with increasing shear rate. The frequency of collision between two asphaltene particles ($\omega$) in the presence of Brownian diffusion can be determined using the following expression [5]:

$$\omega = 4\pi(D_1 + D_2)(R_1 + R_2)N_0 , \qquad (1)$$

where $D_i$ and $R_i$ are the diameter and radius of *i*-droplets, respectively; and $N_0$ is the initial number of droplets in a unit volume.

Formation of aggregates from asphaltene particles also occurs in pipelines at intensive turbulent oil flow. The frequency of particle collisions during isotropic turbulent oil flow in pipes is determined by turbulence parameters, capture coefficient, and physical and chemical properties of oil and asphaltenes. In the works [6], expressions for frequency of coagulation and crushing of particles in isotropic turbulent flow due to turbulent diffusion of particles are given in the following form:

$$\omega(a) = C_0 N_0 a^3 \left(\frac{\varepsilon_R}{\nu_c}\right)^{\frac{1}{2}} \exp\left[-C_1 \frac{\sigma}{(\nu_c \varepsilon_R)^{\frac{1}{2}} a \rho_c}\right], \qquad (2)$$

where a is the size of droplet; $C_0$ and $C_1$ are the initial and current concentration of the component, respectively; $\varepsilon_R$ is the specific dissipation of energy per unit mass; $\nu_c$ and $\rho_c$ are the kinetic viscosity and density of the medium, respectively; and $\sigma$ is the surface tension coefficient.

It follows from this expression that the higher the oil viscosity, the lower the collision frequency and the lower the probability of formation of coagulation aggregates. Particles of asphaltenes enlarging due to coagulation, reach the maximum size of unstable aggregate. After that their crushing begins. It can be assumed that under the action of hydrodynamic forces all bonds between particles in the aggregate are stretched to a critical value, as a result of which this aggregate initially breaks up into aggregates of smaller size, and further there is a secondary, tertiary, etc. breakup down to a single particle. Destruction of coagulation structures formed by paraffins and asphaltenes in general determines the transportability of oil emulsion through pipes and in the bulk of oil in equipment. In the limiting case of infinite shear rate $\tau >> \tau_0$, complete destruction of aggregates down to a single particle is possible and the flow of such oils or oil emulsions can be considered as the flow of dispersed liquids. Since the effective viscosity $\eta_{eff}$ depends on temperature and shear rate (pressure gradient), additional energy expenditure will be required to break the structure during the initial injection period. It should be noted that after the load is removed, the strength of the structure spontaneously recovers fully and the viscosity takes the maximum value, i.e. a certain thixotropy is observed.

It should be noted that thixotropic properties are characterized by oils and oil products with a high content of asphaltene-resin substances, which are usually described by the Herschel-Bulkley $\tau = \tau_0 + k_0\dot{\gamma}^n$ rheological equation and the Ostwald-de Bill stepping law $\tau = k_0\dot{\gamma}^n = k_0\dot{\gamma}^{n-1}\dot{\gamma}$. However, at high shear rates the Bingham equation $\tau = \tau_0 + \eta\dot{\gamma}$ is valid (where $k_0$ is the consistency coefficient; $\dot{\gamma}$ is the velocity gradient; and $\eta$ is the viscosity of the medium) [7], which is the main equation for describing anomalous oils, including heavy oils. The above facts significantly affect the separation of anomalous oil emulsions, creating nonlinearity of their description. At the same time, it should be noted that despite a large number of publications offering various approaches in the field of rheology of structured oils, there is still no satisfactory theory linking rheological coefficients with structural-rheological properties of oil, namely, with interaction forces between asphalt tar and paraffin particles, shear stress, structure of disordered structures and size of aggregates.

Experimental and theoretical studies indicate that the structure of the intermediate layer is very complex in terms of disperse composition (stratification) and physical phenomena (coalescence, deformation, and crushing). Theoretical and experimental studies of the mechanism of formation of stabilization and destruction of oil emulsions as heterogeneous media are devoted to a number of works [8], although many problems related to the phenomena occurring at the oil-water interface, coalescence and crushing of water droplets, stratification and sedimentation have not found their correct solution.

The aim of this work is structural analysis of the state, experimental study and development of algorithms to describe physical phenomena using elementary acts of rheology of highly viscous liquids occurring in the processes of separation of oil emulsions.

## Results and discussion

Considering the above, high-viscosity oil emulsions involve structure formation due to the high content of asphaltene-resin substances due to the processes of coagulation and coalescence. The mechanism of destruction and separation of oil emulsions is based on the following physical phenomena:

(i) hydrodynamic interaction and collision of droplets of different sizes with formation of interfacial film. It should be noted that droplet transport in polydisperse medium is determined mainly by hydrodynamic conditions and turbulence of the flow. Under isotropic turbulence conditions, the droplet collision frequency depends on the specific energy dissipation of the turbulent flow, properties of the medium and the dispersed phase;

(ii) formation, deformation and destruction of adsorption layers at the oil-water interface in the bulk of flow at certain temperatures and pressures using various demulsifier reagents;

(iii) formation of an intermediate dynamic layer comprising droplets in dynamic equilibrium. The structure of the pulsating intermediate layer is determined by the concentration and size of droplets, which obey the conditions of dynamic equilibrium of all forces acting on the droplet and providing sedimentation stability. At large porosity values the layer breaks down and droplets are carried away by the flow. Since the thickness of the intermediate layer is very sensitive to the flow velocity, it is possible to intensify the process by pulsation change of velocity, i.e. the best conditions for droplet collision and coalescence appear at compression, and favorable conditions appear for droplet sedimentation at expansion up to a certain height. At the same time, the intermediate layer in the process of oil emulsion separation has filtering properties, trapping in its bulk not only finely dispersed droplets, but also other impurities released due to the adsorption layer destruction;

(iv) thinning and rupture of the interfacial film, followed by merging and enlargement of droplets. The interfacial film rupture favors the merging of smaller droplets into larger ones. It is important to note that due to oil emulsion transport in pipes, the droplet crushing rate is much higher than the coalescence rate, resulting in an oil emulsion characterized by a wide dispersion of droplet sizes and significant polydispersity of the medium;

(v) precipitation and separation of droplets and separation of dispersed phase as a continuous phase. The intensification of flow and separation of oil emulsions is primarily related to the rheological properties of the oil emulsion and flow turbulization. High-frequency turbulent pulsations contribute to mechanical weakening of adsorption and interphase film and intermolecular bonds between its components and decrease of film strength as a result of its deformation (stretching or compression), as well as improve the efficiency of mutual collision of droplets with their further coalescence, enlargement and sedimentation.

The formation of adsorption layer on the surface of water droplets is connected with diffusive mass transfer of asphalt-tar and paraffin compounds from the bulk of oil to the surface of water droplets. As a result of the solution of the mass transfer equation [9], the mass flux of asphalt-tar compounds on the surface of a moving drop per unit time for Reynolds number $\mathrm{Re}=\frac{Ua_r}{\nu_c}<<1$ is determined as follows:

$$I=\sqrt{\frac{4\pi}{3}}\left[\frac{D}{a_r}\cdot\frac{\eta_c}{\eta_c+\eta_d}\right]^{1/2}a_r^2\Delta C\sqrt{U}\,, \tag{3}$$

where $\eta_c$ and $\eta_d$ are the are viscosities of medium and drop, respectively; D is the molecular diffusion coefficient; $\Delta C=C_0-C_S$, $C_0$ and $C_S$ are the contents of asphaltenes and resins in the bulk and on surface, respectively; and U is the speed of movement of drop.

For heavy oils with high content of asphaltenes and resins, the thickness of adsorption layer will be significant. Formation of an adsorption layer on the surface of water droplets with elastic and viscous properties contributes to the stabilization of oil emulsions. Despite the insignificant thickness of the adsorption layer compared to the size of the droplet, their strength on the surface of the droplets for different oils varies between 0.5 and 1.1 N/m$^2$ [10], as a result, the droplets behave as solid particles.

When a viscoplastic drop (asphaltenes and resins) of a highly viscous liquid interacts with a drop of ordinary liquid (water), the drops do not merge. The viscoplastic liquid flows around the drop, forming an adsorption layer on the surface of the ordinary drop with the thickness $\Delta$ (Fig. 1). The transfer of a non-Newtonian droplet to the surface of an ordinary droplet occurs by diffusion, as a result of which the thickness of the adsorption film depends on the diffusion coefficient and the content of non-Newtonian droplets in the bulk (3). In particular, for oil emulsions, the adsorption film is formed by diffusion of asphaltene-resin substances to the surface of water droplets. Based on the mass balance, for spherical droplets in the limit steady state, we can write:

$$m_s = m_0 + m_k \,, \tag{4}$$

where $m_s$, $m_0$ and $m_k$ are the masses of the attached drop, a normal drop and a drop of non-Newtonian fluid, respectively.

Taking into account the spherical shape of droplets, we define the thickness of adsorption layer from (4) in the following form:

$$\Delta = \left( \frac{\rho_s}{\rho_k} R_s^3 + \frac{\rho_w}{\rho_k} R^3 \right) - R \,, \tag{5}$$

where $\rho_s$, $\rho_k$, and $\rho_w$ are the densities of the liquid of the attached drop, non-Newtonian, and ordinary liquid, respectively; $R_s$ and R are the radii of the attached drop and ordinary drop, respectively.

The above stages associated with the formation of coagulation structures form the basis of structural change in the «oil–water» system.

Non-Newtonian fluid flow occurs mainly due to internal flow in a normal drop. As a result, to destroy the adsorption film, some reagents (demulsifiers) are used, the consumption of which should be determined by the thickness and mass of the layer.

The formation of an adsorption film on the surface of water droplets provides significant resistance to their merging at collision, which leads to aggregatively stable emulsions. The subsequent stages of emulsion separation (coalescence, consolidation and precipitation) occur after the film is destroyed by various reagents. The mechanism of adsorption films destruction consists in diffusive transfer of demulsifier to the film surface, with further adsorption and penetration into the film bulk, formation of defects and cracks in its structure, change of surface tension and reduction of strength properties, which qualitatively changes rheological properties of films at the oil–water interface.

Crushing and coalescence of water droplets in oil emulsions are important physical phenomena that determine the effective stratification of the system. These phenomena determine the size spectrum of water droplets, creating an intermediate layer in the apparatus ($\alpha<50$ μm) with inherent properties and determining the efficiency of emulsion stratification. Oil emulsions are polydisperse media with water droplet sizes of 1–150 μm, although coarse disperse (150–1000 μm) and colloidal (0.001–1 μm) particles are found in them. Coalescence is characterized by diffusive transport and droplet collision frequency, which for conventional oils is determined by expressions (1) and (2). For high-viscosity pseudoplastic fluids taking into account specific dissipation of energy at damping of isotropic turbulence $\lambda<\lambda_0$ (where $\lambda$ is the scale of turbulent pulsations and $\lambda_0$ is the Kolmogorov scale of turbulence), the diffusion coefficient is represented as follows:

$$D_T \approx \alpha \left( \frac{k_0 \dot{\gamma}^{n-1}}{\eta_{eff}} \right)^{1/2} r^2 \,, \tag{6}$$

where r is the radial coordinate; and $\alpha$ is the proportionality coefficient.

A large number of empirical formulae for calculating the dependence of effective viscosity on the content of water and particles of dispersed medium are given in refs. [11], and depending on the content of asphalt-resinous substances in oil in ref [12].

It follows from expression (6) that as the viscosity of the medium increases, the diffusion coefficient decreases, and the diffusive transfer is attenuated in proportion to $\eta_{eff}^{-1/2}$ for highly viscous liquids. The process of droplet coalescence can be considered as a diffusive transfer of a set of droplets through an imaginary spherical surface of radius $R_m = (1.5-2)R$ to a selected central particle, in connection with which, the change in the number of particles taking into account the diffusion coefficients (6) in spherical coordinates can be written as follows:

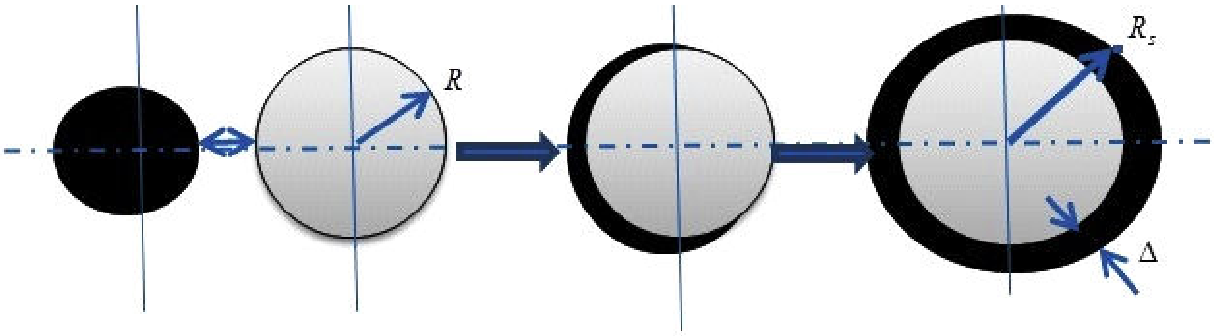

Fig. 1. Interaction of a non-Newtonian drop with a drop of ordinary liquid

$$\frac{\partial N}{\partial t} = \alpha\left(\frac{k_0\dot{\gamma}^{n-1}}{\eta_{eff}}\right)^{1/2}\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^4\frac{\partial N}{\partial r}\right);$$
$$t = 0,\ \ r > R_m,\ \ N = N_0;$$
$$t > 0,\ \ r = R_m,\ \ N = 0; \qquad (7)$$
$$t > 0,\ \ r \to \infty,\ \ N = N_0;$$

where N is the number of droplets in a bulk unit.

The solution of this equation at the given boundary conditions allows determining the diffusion flux or frequency of droplet collisions in the following form:

$$J = -4\pi R_m^2 D_T \left.\frac{\partial N}{\partial r}\right|_{r=R_m} =$$
$$= 4\pi R_m^2 N_0 k\alpha\left(\frac{k_0\dot{\gamma}^{n-1}}{\eta_c}\right)^{1/2}\exp\left(-\alpha\left(\frac{k_0\dot{\gamma}^{n-1}}{\eta_c}\right)^{1/2}\mu^2 t\right), \quad (8)$$

where $\mu$ is the collision number; and t is the time.

If a part that all particles crossing the imaginary sphere collide with high probability and merge with the central particle, then $\omega = J$ which represents the collision frequency. For instantaneous coalescence of two drops, this expression is simplified to the form $(R_m = 2R)$:

$$\omega = \beta R^3 N_0\left(\frac{k_0\dot{\gamma}^{n-1}}{\eta_{eff}}\right)^{1/2}, \quad (9)$$

where $\beta$ is the mass transfer coefficient.

Let's define the change of average droplet mass in the following form:

$$\frac{dm}{dt} = \omega(m - m_{max}), \quad (10)$$

where $m_{max}$ is the mass of a drop corresponding to its maximum size (150–200 μm).

Under the action of the gravitational field, only sufficiently large droplets (≥100 μm) settle down.

Based on rheological models for viscous and highly viscous fluids, we can take into account that $\eta_{eff} = k_0\dot{\gamma}^{n-1}$, resulting in the Morton number $Mo = \frac{g}{\rho_c\sigma^3}\left(k_0\dot{\gamma}^{n-1}\right)^4$, Reynolds number for a droplet $Re_d = \frac{\rho_c\dot{\gamma}R^2}{\eta_{eff}} = \frac{\rho_c U^{2-n}R^n}{k_0}$, and Weber number $We = \frac{\rho_c\dot{\gamma}R^{n+1}U^{2-n}}{\sigma} = We_0\left(\frac{\dot{\gamma}R}{U}\right)^n$ (where $g$ is the free fall acceleration; $\sigma$ is the surface tension; $We_0$ is the Weber number for ordinary liquids, which is an important number to evaluate the behavior of droplets in emulsions).

The given numbers play an important role in deformation and fragmentation of droplets, in their coalescence, enlargement, sedimentation and stratification for high-viscosity oils. Figure 2 shows the droplet settling velocity as a function of their size at different Morton numbers.

For highly viscous oils, the number turns out to be quite large, which reduces the sedimentation rate, thus increasing the residence time.

The process of water separation from oil is described by the convective diffusion equation in the following form:

$$V\frac{\partial C_w}{\partial x} = D\frac{\partial^2 C_w}{\partial x^2}, \quad (11)$$

where $C_w$ is the amount of water in oil; and x is the vertical coordinate.

Given that $dt = dx/V$, we can rewrite equation (11) in the form:

$$\frac{\partial C_w}{\partial t} = D\frac{\partial^2 C_w}{\partial x^2};$$
$$t = 0,\ \ C_w = C_{w0}; \qquad (12)$$
$$t \to \infty,\ \ C_w = C_{w\infty}.$$

By introducing a new variable $\xi = x/\sqrt{4Dt}$, the solution of (12) is represented in the form:

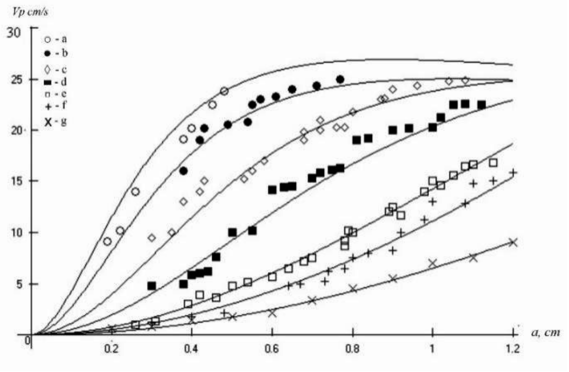

Fig. 2. Deposition rate of droplets in different media as a function of their size and Morton number equal to: (a) $9{\cdot}10^{-7}$; (b) $10^{-4}$; (c) $9{\cdot}10^{-4}$; (d) 0.023; (e) 1.4; (f) 7.0; and (g) 78.0

$$C_w(t)=C_{w\infty}+(C_{w0}-C_{w\infty})(1-\mathrm{erf}(\xi))\,. \quad (13)$$

Using our own formula [2]

$$\mathrm{erf}(\xi)=1-\exp\left(-\xi-\frac{\sqrt{\pi}}{2}\xi^2\right), \quad (14)$$

expression (13) will be represented as

$$C_w(t)=C_{w\infty}+(C_{w0}-C_{w\infty})\exp\left(-\xi-\frac{\sqrt{\pi}}{2}\xi^2\right). \quad (15)$$

Equation (15) determines the distribution of water quantity over time and over the height of the apparatus, taking into account gravitational settling of droplets.

Several experimental studies have been carried out to separate emulsions of Azerbaijani high-viscosity oil using demulsifiers. The experiments were carried out for different amounts of demulsifier (0–600 mg/l) at different temperatures (20–60°C) for 2 hours. Table summarizes the relevant results of the studies.

At experimental study under laboratory conditions, many physical phenomena (convective-diffusive transfer, formation of intermediate layer, etc.) can be neglected, which significantly simplifies the description of the process. The description of the experimental process is based on the equations of convective-diffusive transport of water mass from the oil bulk as a function of demulsifier flow rate and temperature in the form of eq. (15). By substituting $\xi=k(C_w,T)t$ (where $k=V^2/D$), the solution of eq. (15) ) can be represented in the following:

$$C_w(t)=C_{w\infty}+(C_{w0}-C_{w\infty})\exp\left(-kt-\frac{\sqrt{\pi}}{2}k^2t^2\right), \quad (16)$$

where $C_{w\infty}$ is the limit content of residual water in oil; $C_{w0}$ is the initial water content in oil, $C_{w0}=41\%$ for this oil; and $\xi=k(C_w,T)$ is the kinetic coefficient, which is the inverse of the relaxation time of the sedimentation rate and depends on the amount of demulsifier and temperature.

Using the experimental data, a semi-empirical formula was obtained:

$$k=3\cdot10^{-5}\exp(0.033(T-T_{20})+0.0035C_w)\,. \quad (17)$$

Figure 3 shows the curves of comparison between experimental and calculated values.

### *Conclusions*

Thus, in this work, the structural analysis of physical phenomena in the processes of separation of heavy oil emulsions is considered, covering the main stages of the processes of water removal from oil. The problem of formation of adsorption layer of asphalt-resin compounds on the surface of water droplets, the mass of which determines the demulsifier flow rate, is discussed. Models of diffusive transfer of asphalt-resin compounds to the surface of a water drop (3) and the character of flowing of high-viscosity substances over the drop surface with formation of an adsorption layer sre developed. The problems of water droplet

**Results of experimental studies of oil emulsions separation from water**

| Time of the process, min | Residual water, % | | | | | | |
|---|---|---|---|---|---|---|---|
| | amount of demulsifier, mg/l | | | | | | |
| | 0 | 100 | 200 | 300 | 400 | 500 | 600 |
| $30^0C$ | | | | | | | |
| 20 | 40.0 | 39.6 | 37.8 | 37.5 | 37.1 | 36.7 | 35.9 |
| 40 | 38.4 | 38.3 | 36.4 | 35.7 | 34.6 | 33.4 | 32.1 |
| 60 | 37.8 | 36.4 | 33.8 | 30.8 | 29.7 | 28.1 | 26.3 |
| 80 | 36.6 | 34.3 | 30.1 | 26.8 | 24.5 | 22.7 | 20.3 |
| 100 | 35.4 | 30.9 | 27.8 | 23.7 | 21.1 | 17.6 | 12.4 |
| 120 | 33.1 | 28.7 | 25.6 | 21.5 | 18.4 | 12.2 | 8.6 |
| $50^0C$ | | | | | | | |
| 20 | 38.5 | 37.6 | 34.5 | 33.4 | 32.6 | 31.9 | 31.4 |
| 40 | 36.4 | 33.8 | 28.8 | 26.5 | 25.4 | 24.7 | 24.2 |
| 60 | 33.6 | 26.0 | 22.6 | 18.7 | 17.6 | 16.9 | 16.4 |
| 80 | 31.4 | 20.2 | 16.8 | 9.5 | 8.7 | 8.0 | 7.5 |
| 100 | 29.7 | 17.5 | 11.5 | 4.1 | 3.4 | 2.7 | 2.2 |
| 120 | 29.0 | 15.1 | 6.4 | 1.9 | 0.91 | 0.35 | 0.07 |

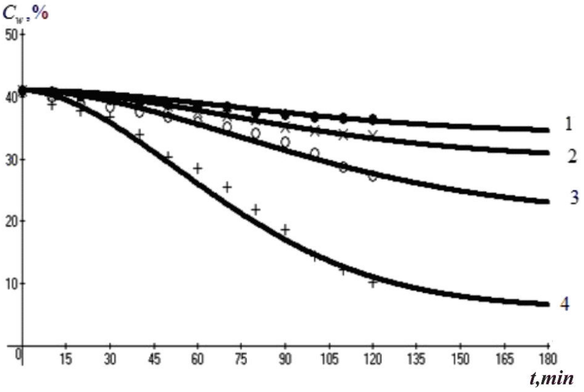

Figure 3. Comparison between calculated and experimental values of volumetric removal from oil at $T$=20$^0$C and at different demulsifier flow rates (mg/l):
(1) 0; (2) 100; (3) 300; and (4) 600

coalescence after adsorption layer destruction have been considered and the frequency of droplet collision is determined depending on the process conditions (7)–(9). A number of experimental studies of separation processes of heavy Azerbaijani oils using different amounts of demulsifier (0–600 mg/l) and at different temperatures (20–60$^0$C) are given. Calculation models of separation process in «water–oil» system (15) and (16) are proposed and calculated results are compared with experimental data.

It is shown that the formation of adsorption film on the surface of water droplets provides a significant resistance to their merging at collision, which leads to aggregatively stable emulsions. The subsequent stages of emulsion separation come after the film is destroyed by various reagents. The equations of coalescence at collision of a high-viscosity droplet with an ordinary one are proposed and expressions for calculation of the droplet collision frequency are obtained. Experimental studies of oil emulsions separation processes are carried out. It is established that in the experimental study many physical phenomena can be neglected, which significantly simplifies the description of the process. The description of the experimental process in the form of a model is based on the equations of convective diffusion transfer of water mass from the amount of oil as a function of demulsifier flow rate and temperature. Comparison curves of experimental and calculated values are given.

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## СТРУКТУРНИЙ АНАЛІЗ ТА ЕКСПЕРИМЕНТАЛЬНЕ ДОСЛІДЖЕННЯ ПРОЦЕСІВ РОЗДІЛЕННЯ НАФТОВИХ ЕМУЛЬСІЙ З ВИКОРИСТАННЯМ РЕАГЕНТІВ

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У цьому дослідженні надано структурний аналіз фізичних явищ, які мають місце у процесах розділення нафтових емульсій. Розглянуто різні аспекти утворення адсорбційного шару на поверхнях крапель, що формуються асфальтосмолистими сполуками, а також запропоновано моделі для розрахунку маси та товщини цього шару. Показано, що утворення адсорбційних плівок на поверхні водяних крапель забезпечує значний опір їх злиттю при зіткненні, що призводить до формування агрегативно стійких емульсій. Розділення емульсій відбувається на наступних стадіях після руйнування цих плівок за допомогою різних реагентів. Механізм руйнування адсорбційних плівок включає дифузійне перенесення демульгаторів до поверхні плівки, їх подальшу адсорбцію та проникнення у об'єм плівки. Запропоновано рівняння для опису коалесценції під час зіткнення краплі високої в'язкості зі звичайною краплею, а також отримано вирази для розрахунку частоти зіткнення крапель. Здійснено експериментальні дослідження процесів розділення нафтових емульсій. Встановлено, що у рамках експериментального дослідження багато фізичних явищ (конвективне дифузійне перенесення, утворення проміжного шару тощо) можна знехтувати, що значно спрощує опис процесу. Опис експериментального процесу у вигляді моделі базується на рівняннях конвективного дифузійного перенесення маси води з нафтового об'єму залежно від витрати демульгатора та температури. Для перевірки моделі наведено порівняльні криві експериментальних і розрахункових значень.

**Ключові слова**: нафтова емульсія; адсорбційний шар; коалесценція; вода; експеримент; осадження; демульгатор; високов'язка нафта.

## STRUCTURAL ANALYSIS AND EXPERIMENTAL STUDY OF OIL EMULSION SEPARATION PROCESSES INVOLVING REAGENTS

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This study presents a structural analysis of the physical phenomena involved in the processes of oil emulsion separation. Various aspects of adsorption layer formation on droplet surfaces by asphaltene-resin compounds are discussed, along with models for calculating the mass and thickness of the layer. It is demonstrated that the formation of adsorption films on the surface of water droplets provides a significant resistance to their merging at collision, resulting in aggregatively stable emulsions. Emulsion separation occurs in subsequent stages following the destruction of these films using various reagents. The mechanism of adsorption film destruction involves the diffusive transfer of demulsifiers to the film surface, followed by their adsorption and penetration into the film's volume. Equations describing coalescence during the collision of a high-viscosity droplet with an ordinary one are proposed, and expressions for calculating droplet collision frequency are derived. Experimental studies on oil emulsion separation processes have been conducted. It is established that in the experimental study many physical phenomena (convective diffusion transfer, formation of intermediate layer, etc.) can be neglected, which significantly simplifies the description of the process. The description of the experimental process in the form of a model is based on the equations of convective diffusion transfer of water mass from the bulk of oil as a function of demulsifier flow rate and temperature. Comparison curves of experimental and calculated values are given to validate the model.

**Keywords:** oil emulsion; adsorption layer; coalescence; water; experiment; sedimentation; demulsifier; high-viscosity oil.

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