

## ENGINEERING SCIENCES

**DEVELOPMENT OF A PROCESS CONTROL SYSTEM FOR DYNAMIC SEDIMENT OF OIL EMULSION**

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**ABSTRACT**

Using heat balance and geometric features of horizontal cylindrical sedimentation, a new method and algorithm for controlling the dynamic sediment of emulsified water drops of oil emulsion have been developed. The mechanism of oil emulsion dynamic sediment on the proposed method is that the redistribution of the flow contributes to the cyclic change in the flow rate of the oil emulsion in the settling apparatus and the oscillatory motion (compression and expansion) of the intermediate emulsion layers, leading to the destruction of armoring casings, coalescence of emulsified water drops and transfer mechanical impurities into water cushion of the settling apparatus, as a result of which the quality of commercial oil increases (the content of water and mineral salts decrease in the prepared oil) and the risk of flooding the settling apparatus decreases. In the settling apparatus, where the volume of the oil emulsion is greater than the average value, the intermediate emulsion layer expands, the kinetic energy increases, and it increases the efficiency of collisions between the drops, leading to the destruction of the armoring casings and coalescence of the drops. When the volume is less than the average value, the intermediate emulsion layer is compressed, the distance between the drops decreases, leading to a coalescence of the drops and an increase in the efficiency of oil preparation.

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One of the important objects of oil-gas industry is the thermochemical preparation of crude oil produced from oil wells.

The process of oil preparation (POP), including dehydration and desalting of oil emulsion (OE), is carried out at the thermochemical installation of oil preparation (TCIOP) by using heat and chemical reagent – demulsifier. The process of dehydration is mainly carried out in parallel working horizontal cylindrical settling apparatuses (HCSA) in a dynamic mode. In order to improve the quality of OE dynamic sediment, it is necessary to create an effective control system.

At the same time, as noted in [1, 3], the determinative stage in the separation of OE into oil and water is the destruction and removal of armoring casings (AC) from the surface of drops of emulsified reservoir water. The completeness and speed of this stage are decisive in the process of dynamic sediment (PDS) of OE. As it is known, the aggregative stability of OE being associated with the formation of AC causes sulfonic acids, which are anion active of surface-active substances (SAS), mechanical impurities consisting of metal-porphyrin complexes, iron sulphides, particles of fine clay and little dissolved salts, which are hydrophobized asphalt - resinous substances, concentrated on AC of emulsified water drops and prevent their coalescence (4-7).

Obviously, the necessary and expected effects on AC can be provided by the demulsifier only within certain indicators of the properties of these casings, which are characteristic of OE, as the concentration of stabilizing components on the surface of wells to TCIOF deteriorate the effect of the demulsifier.

It should be emphasized that due to insufficient cleaning from mechanical impurities and asphaltenes of drainage water injected into the reservoir to maintain reservoir pressure, it is possible that an increased amount of mechanical impurities (mechanical emulsifiers) and particles of asphaltenes appear in the production of oil wells, which, in turn, is the cause of the formation of intermediate emulsion layers (IEL) in the settling apparatus. This is especially noticeable in the preparation of heavy oils from the late stage of development of oil fields.

**Statement of the problem.** It is known that the main factors determining the effectiveness of PDS, including IEL, are the followings:

- turbulent diffusion of demulsifier molecules to AC (using a centrifugal pump), wetting and destruction of the latter;
- collision efficiency coefficient taking into account the proportion of the total number of possible collisions of EWD, which ends with a coalescence (merger);
- the speed of the dynamic constrained sediment of EWD from the leveling concentrated layer in a layer of dense packaging of EWD (IEL) and from the latter to the layer of water cushion. In this case, the controlling factors are the specific consumption of the demulsifier, the level of the water cushion (WCL) and the temperature of the OE before entering the settling apparatus (SA). In addition, as a controlling factor, the creation of an oscillatory mode can be used in SA, which consists in the uneven distribution of OE flow between concurrently operating SA (while maintaining balance), with an impact on the actuators installed on the flows before each SA.

From the above mentioned, there is a need to create a new similarity criterion, allowing to evaluate the quality of PDS of OE and the control system, to increase the effectiveness of PDS, taking into account the factors listed above.

**The solution of the problem.** In order to solve this task, a system for measuring and controlling the TCIOF process was developed, which is shown in the figure.

In order to improve the quality of the control system of PDS of OE, the following mathematical models (algorithms) were developed.

The differential pressure is measured at the height of AC, and the level of the water cushion is determined according to the following algorithm:

$$h_{wi} = \frac{\Delta P_i - \Delta \rho H_g}{(\rho_w - \rho_o)g} = \frac{\Delta P_i}{(\rho_w - \rho_o)g} - \frac{H\rho_o}{\rho_w - \rho_o}, \tag{1}$$

where  $\Delta P_i$  is the pressure drop over the height of settling between the sensors  $11 i$  and  $12 i$  ( $i = 1, 2, \dots, n$ );  $g$  is acceleration of free fall;  $H$  is the distance between two pressure sensors installed at the height of the settling;  $i$  is SA number;  $\rho_w, \rho_o$  are respectively the density of reservoir water and oil, determined by laboratory.

2. Using the Newton cooling law, the amount of heat  $dQ$  given by the element of the HCSA surface with temperature  $T$  in the environment with temperature  $T_1$  over time  $d\tau$  is determined as follows:

$$dQ = \alpha(T - T_1)dF d\tau$$

$$\alpha = \beta\alpha_w + (1 - \beta)\alpha_o, \tag{2}$$

where  $\alpha, \alpha_w, \alpha_o$  are the heat transfer coefficients of OE, reservoir water and oil;  $\beta$  is water content in HCSA. The semi-circumferential (parabolic) surface of the HCSA is found by the following formula:

$$dF = 2Rl d\left(\arcsin \frac{h - R}{R}\right), \tag{3}$$

where  $R, l$  is the radius and length of the HCSA, respectively,  $h$  is the height of water cushion.

3. The amount of heat  $dQ_2$ , lost OE, flowing vertically ( $dz$ ) during the time  $d\tau$  through the surface under consideration ( $dF$ ) will be as follows:

$$dQ_2 = -CG \frac{dT}{dz} dz d\tau, \tag{4}$$

$$C = \beta C_{w1} + (1 - \beta)\bar{N}; \quad G = G_w \beta + G_o(1 - \beta)$$

where  $C, C_w, C_o$  is the heat capacity of OE, water and oil, respectively;  $G, G_w, G_o$  is the mass of OE, water and oil.

In this connection, the amount of heat released from OE friction during the element  $dz$ . According to the radius HSCA, irrelevant, it is not taken into account in the heat balance.

Thus, equating the formulas (2) and (4), we obtain the equation of heat balance in the HSCA:

$$-CG \frac{dT}{dz} dz d\tau = \alpha(T - T_1) dF d\tau. \tag{5}$$

Reducing both sides of this formula at  $d\tau$  by taking into account formula (3) after integration, under initial conditions  $z = 0, T = T_0$ , we get the followings:

$$\begin{aligned} \frac{T - T_1}{T_0 - T_1} &= A \exp \left[ - \frac{\alpha R l}{GC} \left( \pi + \arcsin \frac{z - R}{R} \right) \right] = \\ &= A \exp \left[ - R_z \left( \pi + \arcsin \frac{z - R}{R} \right) \right]. \end{aligned} \tag{6}$$

where  $R$  is the new similarity criterion proposed by us (dimensionless quantity);  $A$  is the coefficient of compliance.

Taking into account the level of water cushion in the amount of water and oil in HSCA, the heat content and heat transfer of water and oil, formula (6) is transformed and takes the following form:

$$\begin{aligned} k = \frac{T - T_1}{T_0 - T_1} &= A \left\{ \exp \left[ - \frac{\alpha_w R l}{G_w C_w} \left( \pi + 2 \arcsin \frac{h_w - R}{R} \right) \right] + \right. \\ &\left. + \exp \left[ - \frac{\alpha_o R l}{G_o C_o} \left( \pi + 2 \arcsin \frac{R - h_w}{R} \right) \right] \right\}. \end{aligned} \tag{7}$$

where  $h_w$  is determined by the formula (1);  $k$  is an effectiveness factor in PDS of OE.

Thus, the obtained mathematical model allows to estimate the state of the PDS of OE and is an algorithm for controlling the processes of destruction of the armoring casings and the dynamic constrained sediment of EWD OE. This algorithm is implemented as follows.

Using the sensors 5 and 7' - 7" and converters 6 and 8' - 8" the temperature is measured at OE flow at HSCA inlet ( $T_0$ ) and at the outlet of the latter ( $T$ ) and taking into account the ambient temperature (air) in the CUI, the factor (criterion)  $k_i$  of the efficiency of PDS of OE is calculated in each HSCA. Then, the sensors 11', 12', ..., 11", 12" and converters 13' - 13" measure the pressure drop over the height of the HSCA, in the CUI, using the formula (1), the level of the water cushion in each HSCA is calculated and the value  $B$  is determined by the following formula:

$$\beta_i = R l \left( \pi + 2 \arcsin \frac{h_i - R}{R} \right) h_i, \tag{8}$$

and for known values  $C_w, C_o, \alpha_w, \alpha_o$  is the calculated value  $k_i(k_i^p)$  according to the formula (7). As a result of comparing the actual  $k_i^A$  and calculated ( $k_i^p$ ) values of the efficiency factor  $k_i$  A value is evaluated (compliance rate). In this case, the specific consumption of the demulsifier, the level of water cushions in the HSCA, the frequency and amplitude of the fluctuations in the redistribution of OE flow between the HSCA operating in parallel vary depending on the value  $k_i^p$ . When the value is  $k_i^p$  more nominal, deterioration in the quality of the PDS of OE, and an increase in the level of the water cushion and IEL in the  $i^{th}$  HSCA in the CUI, signals are generated that increase the specific flow rate  $D$ , the frequency and amplitude of the IEL oscillations and decrease the water cushion in this settling.

Thus, the obtained mathematical models (1), (7) and (8) are fundamental for improving the quality of management and commercial oil.

In conclusion, it should be noted that using the heat balance in PDS of OE and the geometric characteristics of the HSCA, mathematical models, algorithms and a quality management system for the destruction process of armoring casings and the dynamic sediment of EWD of OE were developed. At the same time, the specific consumption of the demulsifier, the level of water cushions, the

frequency and amplitude of the IEL oscillations in the HSCA vary depending on the calculated value of the efficiency factor of the PDS of OE.

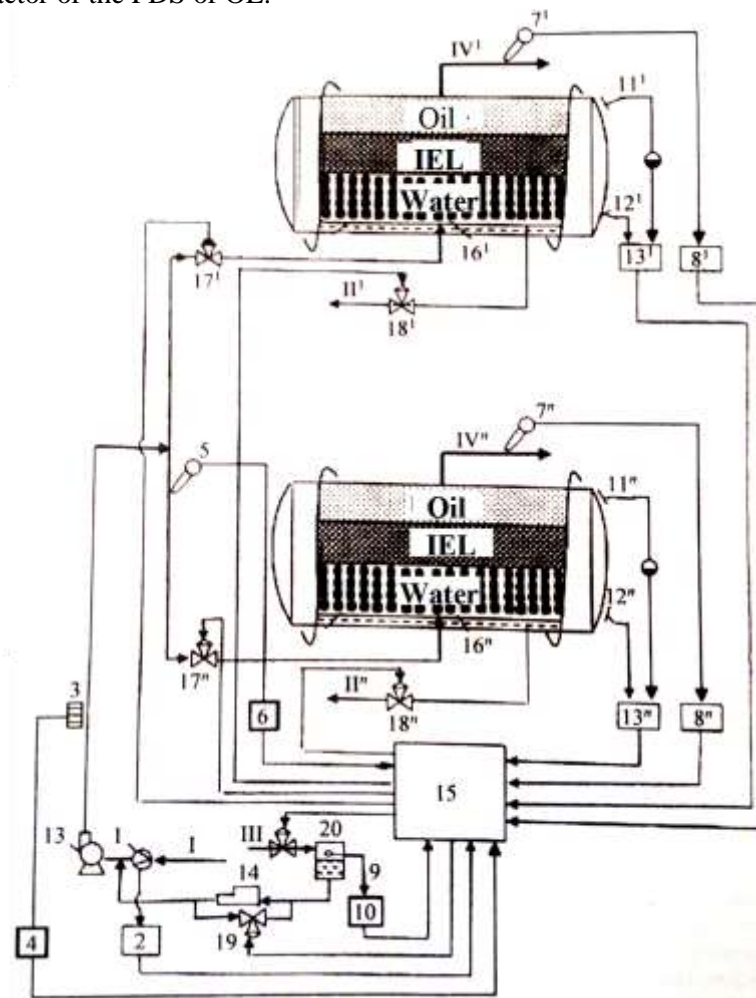


Fig. 1. Process control system for dynamic sediment of oil emulsion

I - OE flow at centrifugal pump inlet; II - drainage water line; III - demulsifier consumption; IV - commercial oil line; 1, 2 - sensors and converters of OE consumption; 3, 4 - sensors and converters of oil emulsion water cut; 5, 6 - sensors and converters of the temperature at inlet of SA; 7' - 7'', 8' - 8'' - sensors and converters of the temperature at outlet of SA; 9, 10 - sensors and converters of levels at demulsifier tank; 11' and 12', 11'' and 12'', 13', 13'' - sensors and converters of pressure falling at the height of SA; 14 - plunger pump of demulsifier (dispenser); 15 - control unit and indication (CUI); 16' - 16'' - SA, 17' - 17'' - actuators installed at OE flow before SA inlet; 18' - 18'' - actuators installed in drainage water line; 19 - actuators installed in bypass line of a plunger pump 14; 20 - demulsifier tank.

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