MATHEMATICAL MODEL OF TERMOCHEMICAL OIL DEEMULSATION PROCESS

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Determining factors of thermo-chemical dehydration process of oil (TDP) are intermediate emulsion layer (IEL) that exists in any settler (S) and residence time (RT) of emulsified water droplets (EWD) in cylindrical horizontal settler (SHS) and ball settling settler (BSS).

IEL, situated between water and oil layers, implements important technological functions. The entire settled water passes through this layer: it facilitates the coalescence process at the interface; inter-drops coalescence may progress in the layer; fine-dispersed component of oil emulsion (OE) can be filtered in it. Its thickness depends on the characteristics of the OE, the flow rate of oil $(v_н)$, the way of admission of OE, the level of water bottoms, etc.

At present adequate models for describing flow specifications DFS do not exist, although there exists a large quantity of researches [1-4] dedicated to their particular cases. Therefore, obtaining an adequate mathematical model of TPS (Tidal Power Station), subject to CAP (Computer-aid Production) EUC in SHS and BSS are urgent problem, which this article is dedicated to.

As it is known, IEL consists of two consistent parts: 1) layer with close packing EUC with the particles of dirt that takes 10-20% of the total height; 2) levelling concentrated blanket that takes the remainder of IEL and is defined almost by linear density gradient, as well as density of EUC in the upper stratum boundaries drop to zero enough sharply (in the absence of up flow).

Being a hydraulic (self-cleaning) filter, IEL facilitates oil's filtration process and may be mathematically described on Darcy law:

$$-gradP = \frac{\mu_e}{K_ф} \, v_н \qquad (1)$$

By using Kozeny-Carman equation of [5]

$$K_f = (1-\varepsilon)^2 S^2 \mu_{eh} v_n h / \varepsilon^3 \Delta P_1 \qquad (2)$$

$$S = 3(1-\varepsilon)\int_0^\infty r^2 f(r)dr \Big/ \int_0^\infty r^3 f(r)dr r^3 f(r)dr \qquad (3)$$

$$\varepsilon = 1 - W = 1 - \Delta P_1 / \Delta P_2 \qquad (4)$$

$$\mu_{eh} = \left(1 + 4\frac{3}{8}\varphi_k^h + \frac{3320}{r^{1,4}\tau^{0,2}}\varphi_h\right)\mu_э \qquad (5)$$

$$\mu_e = \mu\left[1 + \left(1{,}81 + \exp(\tilde{l} - l)\frac{W}{(1/W)^{1/3} - 1}\right)\right] \qquad (6)$$

$$l = 1{,}61 - r\left[(1/W)^{1/3} - 1\right]; \qquad \tilde{l} = 2h_b \qquad (7)$$

where K_f is filtration coefficient; ε, h are accordingly porosity and height IEL; S is specific surface EUC; μ_{eh} - viscosity of the OE system and solid phase; W - water content in IEL; φ_h - solids content; ΔP_1, ΔP_2 - accordingly pressure drop, measurable in the layer IEL and water with the height h, definable on the method worked out by us [6]; μ_e - viscosity OE, definable on formulas (6), (7) [7]; l - distance between the drops; h_b - shell-armoring thickness; r - radius EUC; τ - shear stress; v_n - rising speed of OE and S.

Phase of filtration in IEL causes the process of approach, collision and coalescence of EUC, speed of which is defined from the following balance

$$P = P_h + P_k + P_m = H(\rho_b - \rho)g + \rho\frac{v_n^2}{2} \tag{8}$$

$$P_h = -6\mu v_n \int_R^v \frac{rkdrk}{h^3} \tag{9}$$

$$P_k = (2\sigma_{12}\cos\theta)/r_k \tag{10}$$

$$P_m = 2(\sigma_{23} - \sigma_{13})/h_b' \tag{11}$$

where P - external pressure, squeezing drops; P_h - hydrodynamic pressure, caused by centrifugal pump; P_k - capillary pressure, caused by surface molecular forces; P_m - disjoining pressure, caused by potential energy barrier (with double electrical layer and viscous-mechanical properties of armoured houses EUC), σ_{12}, σ_{23}, σ_{13} - respectively, the surface tension at the borders of phase interface of water-oil, water-mechanical impurity, oil-mechanical impurity; r_k - radius of capillary in IEL.

Our research showed that IEL consists of a number of emulsions (B/H, H/B/H, B/H/B) and is characterized by high content of various mechanical impurities (iron sulphide, clay, etc.). Taking into consideration the above-stated, residual water content in dry oil may be defined on the formula [5, 6]

$$W_1 = (1-\alpha)\int_0^{\tau_k}\int_0^{r_{kp}} f(r,\tau)W_0(\tau)drd\tau \tag{12}$$

$$r_{kr} = (4{,}5v_s(h)\mu/2g\Delta\rho, \qquad \Delta\rho = (\rho_w - \rho) \tag{13}$$

$$\alpha = (W_1 - W_f)/W_1 \tag{14}$$

where α - efficiency factor IEL; ρ_w, ρ - accordingly density of water and oil; v_s - sediment rate EUC; r_{kr} - minimum-drop radius, defined from the terms $v_n - v_s = 0$; W_0, W - correspondingly water content in OE at the enter and exit of S.

An important stage of mathematical formulation of TON process is to define residence time OE in SHS and BHS. To this end, analytical expressions, which derived as follows, are developed. At first it is determined the dependence between v_n in SHS (v_{n1}) and BSS (v_{n2}), and with the geometric dimensioning of the latest, with equations of water blankets (CAP) in them and OE discharge

$$v_{ni}(h_i) = x_1/S_{ni}, i = \overline{1,2} \tag{15}$$

$$S_{h1} = 2l\,n_1\sqrt{h_i^*(2R_1 - h_1^*)}, \quad S_{h2} = \pi n_2 h_2^*(2R_2 - h_2^*), \quad h_i^* = H_i + h_i$$

where x_1 - OE discharge; l - length of SHS; R_1 , R_2 and n_1, n_2 - correspondingly radiuses and numbers of SHA and BSS; h_1^* , h_2^* - total level of CAP and water in IEL SHS and BSS; H_1, H_2 - level of CAP in SHS and BSS. Then we equate differential equation, characterizing throughput rate EUC in oil layer

$$d\left(2R_i - h_i^*\right)/\, d\tau_{di} = v_{ni}\left(h_i^*\right) - v_s , i = 1{,}2 \tag{16}$$

With a glance to (15) equation (16) for SHS and BSS obtains the following state

$$\frac{d\left(2R_1 - h_1^*\right)}{d\tau_{d1}} = x_1 \,/\left(2n_1 l\sqrt{h_1^*\left(2R_1 - h_1^*\right)}\right) - v_s \tag{17}$$

$$\frac{d\left(2R_2 - h_2^*\right)}{d\tau_{d2}} = x_1 \,/\left(\pi n_2 h_2^*\left(2R_2 - h_2^*\right)\right) - v_s \tag{18}$$

Solving equation (17) and (18) with initial terms $\tau_{ki} = 0$ and $2R_i - h_i^* = 0$ we will get:

For SHS:

$$\tau_{d1} = \frac{h_1^* - 2R_1}{v_s} + \frac{x_1}{2v_s^2 n_1 l}\left(\arccos\frac{R_1 - h_1^*}{R_1} - \pi\right) + \frac{x_1^2}{v_s^2 n_1^2 l\sqrt{x_1^2 - 4v_k^2 R_1^2 l^2}}\left(1{,}57 + arctg\frac{x_1\sqrt{h_1^*} - 2v_s n_1 l\sqrt{2R - h_1^*}}{\sqrt{\left(2R_1 - h_1^*\right)\left(x_1^2 - 4v_s^2 n_1^2 l^2 R_1^2\right)}}\right) \tag{19}$$

For BSS:

$$\tau_{d2} = \frac{h_2^* - 2R_2}{v_s} + \frac{x_1}{v_s n_2\sqrt{\pi v_s\left(\dfrac{x_1}{n_2} - \pi^2 v_k^2 R_2^2\right)}} + \left(arctg\frac{\pi v_k\left(R_2 - h_2^*\right)}{\pi v_k\left(\dfrac{x_1}{n_2} - \pi v_s R_2^2\right)} - arctg\frac{-\pi v_k R_2}{\sqrt{\pi v_k\left(\dfrac{x_1}{n_2} - \pi v_k R_2^2\right)}}\right) \tag{20}$$

A residence time of oil molecules in the settling zone of SHS (τ_{01}) and BSS (τ_{02}) may be calculated according to the following proposed formulas:

$$\tau_{01} = \left(n, \frac{l}{x_1}\right)\sqrt{\frac{\left[6R_1\left(2R_1 - h_1^*\right) + \left(2R_1 - h_1^*\right)^2\right]R_1^2}{3}} - \sqrt{\left[2R_1\left(2R_1 - h_1^*\right) - \left(2R_1 - h_1^*\right)^2\right]}\left(R_1 - h_1^*\right) \tag{21}$$

$$\tau_{02} = \pi\left(2R_2 - h_2^*\right)^2\left(R_2 + h_2^*\right)/\,2x_1 \tag{22}$$

Thus, the above-stated formulas (1)-(22) are mathematical models of TON processes, expressing special features to dynamical settling of OE and may be used in development of optimal control processes TON.

Conclusion

The mathematical models of processes TON, which reflect specific features of dynamic settling OE and enable successful solution of problem on optimal control processes of thermo-chemical oil preparation, are developed on the ground of comprehensive analysis of key factors that has impact on the formation and stability of IEL, travel time and velocity gradient of EUC, in SHS and BSS.

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