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Modelling of dewatering and desalting processes for large-capacity oil treatment technology

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Abstract

This paper is devoted to analysis of oil treatment technology in the case of complex industrial process realization and further selection of technological mode. Mathematical modelling method is used to improve the efficiency of dewatering and desalting processes. The simulation system based on module modelling principle is developed. Every module is described in terms of appropriate combination of phenomena and processes. Problems of oil treatment analysis of complex structured technological scheme and searching of effective dewatering and desalting processes technological modes are solved.

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Keywords: Mathematical modelling; Oil treatment plant; Dewatering; Desalting

1. Introduction

Operating experience of oil treatment plants (OTP) demonstrates wide variety of technological equipment and different physicochemical properties of water-in-oil emulsions[1,2]. Several parallel processing train using different equipment suite, which provides required quality of commercial oil, characterizes large-capacity industries. Technological modes of parallel processing trains equipment can differ. Optimization of technological modes and development of designed plant technology improve efficient plant operation. In every definite case the problems of mathematical modelling, optimization and management of oil treatment technological process should be solved. This

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fact determinates actuality of our work aimed at rationalization of dewatering and desalting technological processes using mathematical modelling method in the context of system approach. From this standpoint oil treatment processes are combination of interactive elements of technological scheme.

The simulation systems (SS) are effectively used to solve assigned problems. At the same time these SS are not always appropriate, because it requires much time and material costs. Besides, standard SS cannot be used for technological calculations of oil dewatering and desalting processes. We developed SS of oil treatment[3,4], in which module principle of technological scheme vessel models formation is realized.

The purpose of this work is analysis of oil treatment technology in the case of complex industrial process realization and further selection of technological mode using mathematical modelling method.

2. Subjects and methods of research

2.1. Technological scheme

Variety of oilfield feed and product characteristics limits possibility of typical technological schemes and vessels[5,6,7,8]. Such situation requires differentiated approach in every definite case. However, in the context of system approach any technological scheme can be presented as interaction of following elements: separation, formation of droplets, dewatering and desalting. Every element is characterized by specific composition of phenomena and processes, which behavior laws are described enough in literature[9,10,11,12].

The technological scheme of oil treatment process of Eastern Siberia oilfield has complex structure of streams, high productivity and consists of numerous equipment. Selection of technology is also determined by physicochemical characteristics of crude oil (Table 1, 2).

Table 1. Componentwise composition of crude oil.

Component	Methane	Ethane	Propane	I-butane	N-butane	I-pentane	N- pentane	Hexane +	N_2
Content, mole%	43.97	8.81	5.74	1.16	2.79	1.43	1.63	33.61	0.86

Table 2. Physicochemical properties of oil and technological parameters of basic calculation variant.

Physicochemical properties of oil and technological parameters	Value
Density, kg/m^3	864.10
Kinematic viscosity coefficient at 20°C, mm^2/s	29.54
Molecular mass, g/mole	292
Water cut of crude oil, wt.%	20
Plant productivity, t/yr	$8.4 \cdot 10^6$
Stream ratio of processing trains	60:40

The technological scheme is illustrated on the Figure 1. The OTP is divided in three main processing trains. The first processing train is directed to three phase separators (TPS), which give oil degasified and dewatered. Then untreated oil stream heats up in heater and goes through buffer, where the separation process takes place. In electrical dehydrators (EDH) droplets of water are affected by electric field that causes aggregation of the droplets.

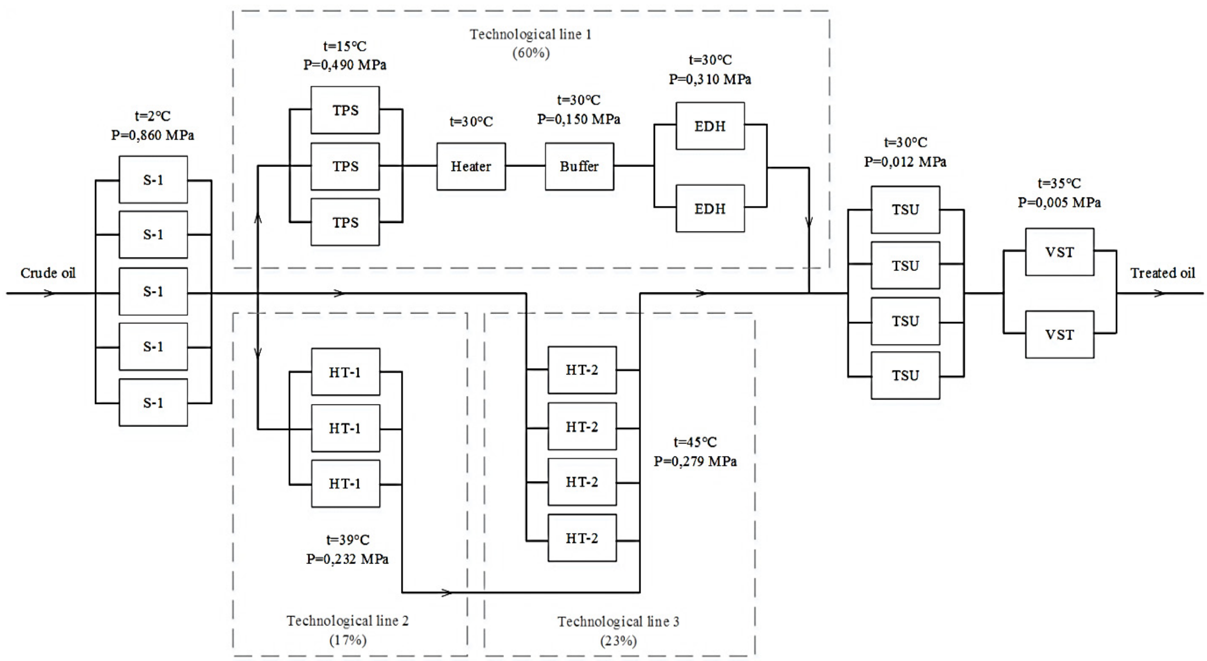


Fig. 1. Block diagram of OTP: S-1 – first stage separator; TPS – three phase separator; EDH – electrical dehydrator; HT-1 – "Heater Treater" without electrical dehydrator element; HT-2 – "Heater Treater" with electrical dehydrator element; TSU – terminal separation unit; VST – vertical steel tank

The second processing train consists of modern complex block installations (HT-1), in which crude oil heats up and separation and dewatering processes are carried out. The third processing train includes similar installations (HT-2), but these "Heater-Treater" vessels have more heat potential and electrical dehydrator element.

We propose the specification of hierarchical structure of oil treatment technology modelling, which is shown on the Figure 2. This approach allows to integrate basic processes into vessels models and technological scheme.

According to technological scheme the calculation scheme is formed in SS. The calculation scheme contains several main modules: first stage separators (S-1), three phase separators (TPS), complex oil treatment installation type of "Heater Treater" (HT-1, HT-2), terminal separator units (TSU), coalescers, electrical dehydrators (EDH), vertical steel tanks (VSH). Processes of separation, droplet formation, dewatering and desalting take place in these modules.

2.2. Modules of SS

2.2.1 Module of separation process

Initial data: plant productivity, composition and molecular mass of crude oil, densities and viscosity coefficients of components, thermobaric parameters.

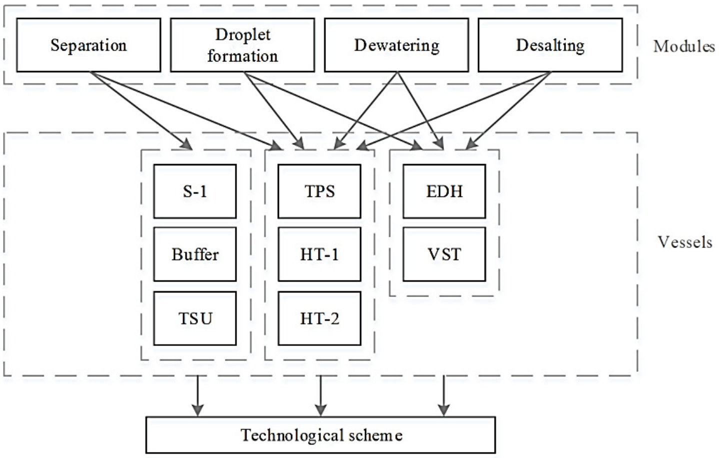


Fig. 2. Hierarchical structure of oil treatment technology modelling

The main equations of calculation of multicomponent mixture separation are shown below (1):

$$\begin{cases} \sum_{i=1}^{m} x_i = \sum_{i=1}^{m} \frac{c_i}{1+e(K_i-1)} \\ \sum_{i=1}^{m} y_i = \sum_{i=1}^{m} \frac{K_i c_i}{1+e(K_i-1)} \end{cases} \tag{1}$$

In this system of equations: c_i, x_i, y_i, – mole fraction of component in feed, output liquid and steam phases respectively; e – steam molar fraction in the end of flashing evaporation process; K_i – phase equilibrium constant of component.

The calculation results are compositions of gas and liquid phases, physicochemical properties of streams, mass balance of separation process.

2.2.2 Module of droplet formation process

Initial data: flowrate of water-in-oil emulsion, physicochemical properties, temperature, water cut of the stream, construction parameters of vessels.

Water droplet diameter in emulsion stream is calculated according to equation[1] (2):

$$d_{max} = 43.3 \frac{\sigma^{1.5} + 0.7\mu_w u^{0.7}\sigma^{0.8}}{u^{2.4} Re^{0.1} \nu_e^{0.1} \rho_o \mu_o^{0.5}} \tag{2}$$

Diameter of water droplet d_{max} depends on interfacial tension on droplet surface σ, dynamic viscosity coefficient of water μ_w, dynamic viscosity coefficient of oil μ_o, density of oil ρ_o and Reynolds criterion Re.

As the result of this module calculation we get diameters of droplets, linear velocity of the stream and criterion of Reynolds.

2.2.3 Module of settling process

Initial data: flowrate of emulsion, physicochemical properties of input stream, temperature, pressure, diameter of droplets, vessel construction parameters.

Oil water cut calculation requires solvation of the following equation[2] (3):

$$(1-w)^{4.7} = \frac{18\omega_h \mu_e (1-w)^2}{d^2(\rho_o - \rho_e) g \left[(1-w)^2 - (1-\frac{w}{w_e})^2\right]} \tag{3}$$

In this equation: w – water cut of output oil stream; w_e – water cut of input emulsion stream; ω_h – hindered settling of droplet with diameter equal d; ρ_e and ρ_o – densities of input emulsion and output oil relatively; μ_e – viscosity coefficient of input emulsion; g – gravity acceleration.

In the end of module calculation we have compositions of gas and liquid phases, physicochemical properties and mass balance of streams, water cut of output oil stream.

Mathematical formulation of processes is developed on the basis of theoretical laws of primary oil treatment processes and this fact guarantee required calculations accuracy and predictive force.

Adaptation of mathematical models realized according to experimental data of industrial OTP. Average relative accuracy of oil water cut is less than 5 %

3. Discussion of results

Using SS mass balances of every vessel and whole OTP are calculated: flowrates of crude oil, associated petroleum gas (APG), treated oil, salt water and sparge water are obtained (Table 3).

Table 3. OTP mass balance

Stream	Crude oil	APG	Treated oil	Salt water	Sparge waterr
Flowrate, t/d	24006	2576	17028	4734	333

The influence of technological parameters on oil dewatering and desalting processes is researched. Variation of technological parameters is shown in Table 4.

Table 4. Variations of technological parameters in OTP calculations

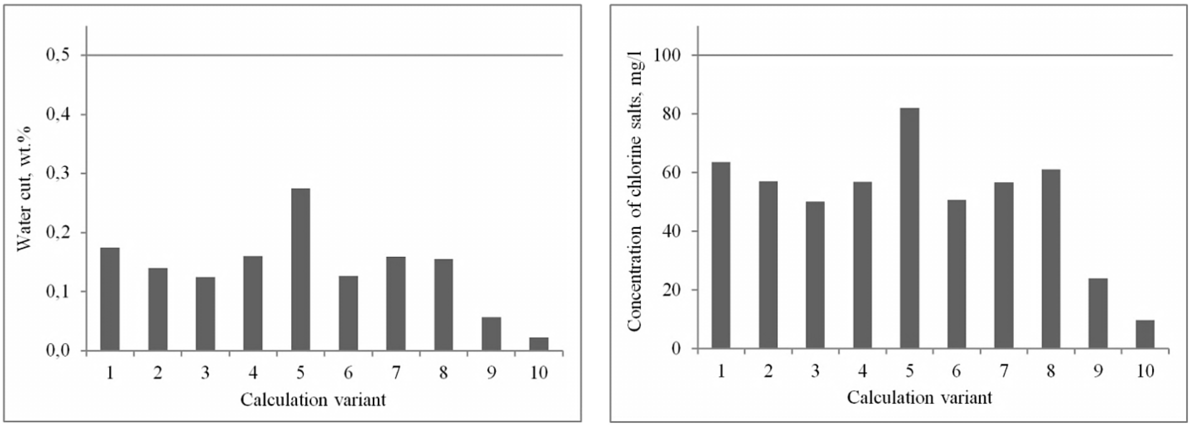
Variant	2	3	4	5	6		7	8	9	10
Vessel	TPS	TPS	HT-1		TPS	HT-1	Technological mode of variant 6			
Variable technological parameter:										
temperature, °C;	25	35	45		25	45				
quantity of TPS;				2			2			
input flowrate of OTP, $\cdot 10^6$ t/yr								8.5	8.0	7.5

Analysis of technological modes of functional industrial plant shows that variation of thermal mode in TPS and HT-1 is the most appropriate and efficient for oil treatment process. Increasing of temperature in HT-1 up to 45 °C improves dewatering process. Varying of temperature in TPS in the range of 15 to 35 °C increases residual water cut down to 0,91 wt.% (Table 5).

Table 5. Water cut of oil stream after treatment in vessel, wt.%

Vessel	Variant									
	1	2	3	4	5	6	7	8	9	10
TPS	2.24	1.39	0.91	2.24	3.76	1.39	2.22	1.51	1.01	0.67
EDH	1.15	0.62	0.37	1.15	2.62	0.62	1.14	0.74	0.3	0.13
HT-1	4.82	4.82	4.82	4.1	4.82	4.1	4.1	4.53	2.77	1.76
HT-2	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.49	1.01	0.67

Variation of residual water cut and chlorine salts concentration in output OTP stream for different technological modes is illustrated on the Figure 3. Results of research show that the most efficient thermal mode is variant 6. In this case residual water cut of treated oil is 0.13 wt.% and concentration of chlorine salts is 50,7 mg/l



(a) (b)

Fig. 3. Quality characteristics of treated oil of calculated technological modes: (a) water cut; (b) concentration of chlorine salts

During operating experience OTP productivity can widely vary. On this basis the influence of material streams flowrate is researched. Decreasing of flowrate leads to reducing of oil residual water cut and concentration of chlorine salts in treated oil.

Industrial plant operation requires deactivation of equipment from technological scheme. Calculations using SS allow to estimate the possibility of production of commercial oil with required quality at the modified structure of technological scheme. Thus, according to results of variants 5 and 7 deactivating of one TPS makes it possible to get necessary quality of oil treatment process.

4. Conclusion

In this work the problems of oil treatment analysis of complex structured technological scheme and searching of effective dewatering and desalting processes technological modes are solved.

The variation of OTP technological parameters permits required residual water cut and concentration of chlorine salts of treated oil. Using SS the calculations results enable to get mass balance at different technological conditions, give recommendations and real-time prognosis of OTP operation during oilfield development.

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