Simulation of oil-gas separator operation

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Abstract. The principle of operation of the oil-gas separator with control of the oil-containing mixture density is described. The mathematical description of the oil-gas separator operation is proposed and the simulation model of the device operation in the MATLAB Simulink program is developed. The mathematical model is based on the interaction of water and oil control circuits. The dynamic model allows us to study the transients in the device, to maintain the degree of water content of the oil-containing mixture at a given level. The algorithm for determining the optimal separation time is developed. Separation process simulation in the program Lite SMO is performed. Implementation of the research results will improve the performance of the oil-gas separator while maintaining the quality of commercial oil.

1. Introduction

Improving efficiency and profitability is one of the priorities of the oil and gas economy sector. One of the most important technological processes in the oil industry is the process of transformation of oil-containing mixture produced from wells into commercial oil. Commodity oil is the production of oil and gas mining company, which has passed the full cycle of preparation and meets the requirements of state standards. Before oil is transported through the oil trunk pipelines, it must be free of water, gas and free from impurities. In this case, the products become suitable for processing into various fuels (diesel fuel, gasoline and kerosene), lubricants, solvents, petrochemical products.

The oil and gas industry in a number of regions of our country has specific features associated with a high degree of water cut. This is especially true of the regions like Middle Volga and Southern Urals. In these conditions, ensuring maximum productivity while maintaining the quality of commercial oil is a serious problem that requires innovative scientific approaches and technical solutions. Therefore, the study of technical devices that support the technological process of oil separation on the basis of their mathematical models is an urgent scientific and technical task.

In view of the high costs of the field experiment, the research of the oil-gas separator is advisable to perform on the basis of its mathematical model.

2. Purpose and principle of oil-gas separator operation

For the organization of the whole complex of technological processes of transformation of oil-containing mixture into commercial oil, a set of methods, technical devices, techniques and algorithms combined within the framework of the oil treatment system (OTS) is used. Choosing the type of OTS depends on many factors [1, 2].

Figure 1 shows a typical OTS. For figure 1 introduced designations: W – wells; BOW – Bush of oil wells, BPS – booster pump station, EM – emulsifier, OGS – oil-gas separator, GTD – gas treatment device, WTD – water treatment device, OTD – oil treatment device, DG – dehydrator, DS – desalination.
Figure 1. Typical scheme of oil treatment system.

The key device of the oil treatment system is the oil-gas separator (OGS). The main function of the OGS is to provide maximum system performance and while maintaining the quality of the output product. Three-phase horizontal OGS with elements of oil-containing mixture density control is described in detail in [3, 4]. The measurement information is supplied to the control unit 13 from the outputs of the emergency sensors 3, 5, liquid level sensors 4, 6 and pressure sensors 9, 11 (figure 2).

Figure 2. OGS with controls and controls.

The actuating elements of the device are water 1, input 2, gas 7 and oil 8 valves. The sensor 10 allows you to adjust the control actions when the temperature changes. Database 12 stores water and oil temperature dependence density information, as well as data relating the density of the oil-containing mixture to its water content to determine the optimal separation time.

3. Mathematical modeling of oil and gas separator control process

For horizontal OGS with gravitational phase separation, the density of the liquid in the chambers is determined based on the ratio:

$$\rho = \frac{p_d - p_n}{g h_l},$$

where $p_d$ – pressure on the bottom, $p_n$ – pressure on the surface, $g$ – acceleration of gravity, $h_l$ – liquid level.

The main tasks arising in the development of the separation process control model are:
- control parameter and choice of the control method description;
- structural and functional control scheme development;
- control object mathematical description;
- impact of external destabilizing factors assessment;
- output characteristics and control quality analysis.
The productivity of the OGS is determined by the volume of oil yield $q_o$ per unit time $t$:

$$ P = \frac{dq_o}{dt} $$  

(1)

The oil yield is associated with the input volume of the oil-containing mixture $Q_{in}$, a set of design parameters of the OGS $S_i$ and the separation time $T_c$ dependence:

$$ q_o = f(Q_{in}, S_i, T_c) $$  

(2)

Separation time, as follows from [4], depends on the degree of water content of the oil and gas mixture in the first chamber of OGS $W_1$:

$$ T_c = \varphi(W_1) $$  

(3)

Density of the oil-containing mixture depends on the degree of its water content. The scientific substantiation of the proposed method of OGS control is the difference in water density (1.0 g/cm$^3$) and oil (0.8 - 0.9 g/cm$^3$).

Maximum permissible water content in the output product in accordance with GOST R 51858 – 2002 is not more than 1% for oil of 2 and 3 groups and not more than 0.5% for oil of 1 group [5]. The analytical solution of equations (1-3) is complicated by many factors - the oil-containing mixture has a complex chemical composition, there is no solution of the Navier-Stokes equation for the non-laminar fluid flow, etc. [6]. Therefore, it seems advisable to perform simulation modeling of the OGS. In the simulation modeling of oil and gas separator, the following main tasks arise: the definition of the control parameter and the control method; the choice of the output parameter; the development of a structural control scheme; the development of a simulation model in the software environment; finding the dependence of the output parameter on the factor as a result of the simulation experiment; analysis of the results.

As a control parameter, the density of the oil-containing mixture associated with the degree of its water content is selected. As an output parameter, the oil consumption is selected, which determines the performance of the OGS.

The block diagram of the automated control of the OGS, based on the measurement and regulation of the density of the oil-containing mixture is shown in figure 3.

The scheme contains two control loops – the outline of the flow of oil and the outline of the flow of water in the first chamber OGS. The input and output processes in figure 3 are related by:

$$ h_{p_o}(s) = \frac{k_o}{s} $$  

(4)

$$ h_{q_o}(s) = q_o \frac{e^{-\tau_o}}{(T_o s + 1)} $$  

(5)

where $k_o$ – the increase in response of the output parameter to the control parameter in the vicinity of the set value, $q_o$ – the volume flow of oil, $T_o$ – the time constant of the oil valve, $s$ – the model time, $\tau_o$ - the delay in the opening-closing of the oil valve. The volumetric flow rate of oil is determined from the ratio:

$$ q_o = k_v f(z) \sqrt{p_1 - p_2} $$  

(6)

where $f(z)$ is a function of the separation time dependence on water degree content of the mixture, $p_1$, $p_2$ – pressure at inlet and outlet of the valves respectively, $k_v$ – coefficient calculated by the formula:

$$ k_v = C_v \sqrt{\frac{2}{\rho_w}} $$  

(7)

in which $C_v$ – valve constant, $\rho_w$ – water density. Similarly, the water volume control circuit is described.
Figure 3. Block diagram of separation process control.

Characteristics of the level of the mixture $H_m(t)$, consumption of oil $Q_o(t)$ and water $Q_w(t)$ in time is presented in figure 4. The graphs illustrate the control of the OGS operation by the $W(t)$ water content parameter. The graph shows that the proposed method allows not only to measure but also to regulate the water content of the oil-containing mixture. This allows to increase the accuracy of the separation time calculation [7] and the stability of the OGS operation, thereby increasing its productivity while maintaining the quality of commercial oil.

Figure 4. Graphs of mixture level, water and oil flow.

Characteristics are based on the relations (4-7) and obtained by means of a simulation model developed in the simulation subsystem of dynamic systems MATLAB Simulink software package. The structure of the simulation model is shown in figure 5.

4. Determination of optimal separation time

Algorithm for automatic determination of the optimal separation time shown in figure 3.

To correct the difference between the temperature expansion coefficients of water and oil, a temperature sensor is additionally introduced into the OGS circuit. Determination of the time of separation is carried out in three stages.

At the first stage, on the basis of the gas pressure, liquid level and hydrostatic pressure sensors, an indirect measurement of the density of the oil-containing mixture takes place. Then the temperature correction of the measurement results is performed.

At the second stage, based on the density measurements of the mixture, a conclusion is made about the degree of its water content. The algorithm provides for constant monitoring of the water content of the oil-containing mixture and updating the initial data for the simulation model.
The third step is the determination of the optimum separation time that is the end result of the work of the entire algorithm.

**Figure 5.** Structure of the simulation model in MATLAB program.
To develop the program, the editor LAD - Ladder Logic in STEP 7 MicroWin was used, which allows to form programs that have a visual similarity with relay-contactor circuits.

5. Simulation modeling of separation process

Simulation modeling of the separation process of oil-containing mixture was carried out using the LiteSMO program. Program is written in the programming language Delphi, supports the mathematical apparatus of Queuing systems, allows you to develop the structure of the simulation model, set the parameters and performs a simulation experiment. The structure of the simulation model is shown in figure 7.

Element "Source DP" mimics the status of the source of the disperse phase, conventionally divided in to six factions. The average diameters of globules in fractions are 50 µm, 60 µm, 80 µm, 100 µm, 150 µm and 200 µm, respectively. The Box-Muller transformation was used to generate a pseudo-random sequence of globules.

Element "Separation mode" selects the value of water content of oil-containing mixture from 70% to 90% with a discrete step of 5%.

Element "Water cut" - simulates the process of coagulation and coalescence of globules in accordance with the selected separation mode.

Element "Laminar flow" is used to check the performance of the simulation model in the test mode. The result of the separation process is taken into account in the elements "Separated DP" and "Residual DP".

The parameters of the simulation model are calculated based on the results of previous studies. Example of a histogram distribution of the time of formation of the solid phase layer of globules of various fractions is presented in figure 8.

The distribution refers to the type of Lifshitz – Slezov distributions with the so-called long tail. The separation time for the third group of oil is determined by discarding the "tail" of the distribution, the
specific weight of which is 1% of the total sample. For example, if the water content is 90%, the optimal separation time will be TS equal 145 seconds with an accuracy of 5 seconds.

![Figure 7. Structure of the separation process simulation model.](image)

Resulting multi-modal histogram with the so-called heavy tail is a mixture of normal distribution laws characteristic of the time of motion of the globules of each fraction under study. The optimal separation time $T_c$ is obtained at the point of clipping the "big tail" of the histogram, to the right of which is 1% of the values of the resulting distribution. The error in determining the separation time was 5 seconds. The percentage value is taken for oil group 3 according to GOST R 51858-2002. For oil groups 1 and 2 it is necessary to toughen requirements to the East of the dispersed phase to 0.5 %.

![Figure 8. Determination of the time separation on the histogram.](image)

6. Summary
1. Model of oil-gas separator in setting the water content of oily mixtures is obtained and studied. Analysis of the results allows choosing optimal separation time, parameters of sensors and actuators, to
automate oil treatment system, to increase productivity while maintaining the quality of commercial oil in accordance with current standards.

2. For the first time, the algorithm for finding optimal separation time based on the calculation of the water content of the oil-containing mixture was developed, the main measurement and computational procedures were determined. The choice of optimal separation time increases production capacity of the oil and gas separator with preservation the quality of commercial oil.

7. References

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