Advanced process control system of oil-gas separator by the temperature channel

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Abstract: Based on the analysis of regulated parameters and control channel a two-level cascade control system of the oil-gas separator was developed. The control system uses data from virtual analyzer of the total calorific value of the fuel gas, the heat content of the emulsion and also the ration of these parameters. Study of the proposed control system was carried on by simulation. The most common scenarios occurring during the operation of the oil-gas separator namely changing the load and other typical perturbing actions were played in order to perform the regulator setting.

Keywords: oil emulsion, ratio controller, cascade control, virtual analyzer.

1. Introduction
Currently, the most of domestic enterprises move to the modern automation equipment and work with advanced process control systems in practice using by technical abilities of microprocessor technologies for the improvement technological and economical effect [1, 2]. Advanced process control systems are wide class of system from extended regulators such as compensators, ratio control systems, Smith predictors and others to multivariable control systems for huge technological objects [3, 4]. The last one includes in a lot of virtual analyzers all of that allow controlling the quality of end products in automatic mode. The accumulated experience of application of advanced process control systems suggests more than 50% decrease the typical deviation of the product specification in comparison with control systems based on the classical control methods.

However, now a day classical control methodologies have not lost their relevance as the simplest in the implementation and well-studied way of regulating technological parameters and are widely used in control systems on the operational level. In work [5] the problem of calculating the parameters of typical regulators for technological processes with several control actions and several output parameters is considered. An automated way of PI and PID regulators setting in the control system with a centralized structure for dynamic objects characterized by the arbitrary dimension, cross links and various delay in the control channels is proposed.

2. Description of the technological process in an oil-gas separator
The crude-oil emulsion is a mixture of oil, associated petroleum gas and deposit water. It inputs in an oil-gas separator either directly from a production oil well, but more often from an oil-dehydration plant [6, 7]. The apparatus heats the emulsion for dehydrating of crude oil and then it knocks down the oil.

The target (output) parameter of a heating system in the oil-gas separator is the oil emulsion temperature, which is measured in a typical scheme of the control system and regulated by changing the consumption of fuel gas. The total amount of oil emulsion suppling to the plant is controlled and varies widely. As a rule, this parameter is not stabilized due to the specifics of the technological process of a crude-oil treatment plant. It is one of the main perturbation influences for the heater
control system. The ratio of the amount of water and oil in the crude-oil emulsion is set by the hydrometric content and also widely varies, affecting on the quality of the regulation.

In order to heat the crude oil emulsion in the oil-gas separator, gas is supplied to the gas-fired burners (in practice, oil-well gas is given off the crude oil in the oil-gas separator and then it supplies to the gas burners). The flow, temperature and pressure of the gas are measured, the flow rate is regulated. Due to an uncontrolled change in the gas composition, the calorific value of the product will be to undergo change.

The air necessary for combustion of fuel gas supplies to the combustion zone naturally. Air parameters namely temperature and humidity affect the process heating the crude oil emulsion, but, as a rule, these parameters are not included in the regulating scheme and treated as additional uncontrolled perturbation influences.

The listed (the list is not complete) factors lead to lower quality of the regulation the oil emulsion heating and also the dehydration process too in traditional automatic control systems. As a result, in general the efficiency of the oil production and treating processes is reduced. Thus, the application of modern control methodologies for the control of the oil-gas separator becomes relevant.

3. Dynamics of the heating process the crude oil emulsion

The dynamics of thermal processes in the heater is quite complicated. A lot of assumptions and simplifications have been done in the mathematical model synthesis of the technological process of the crude oil emulsion heating.

The process of heat transfer from combustion gases to the crude oil emulsion flow is carried out through the thickness and surface of the flame tubes, therefore, the regularities of thermal conductivity and heat transfer will be characteristic for this process. A thermocouple measuring the output temperature of the emulsion is installed in the immediate proximity to the flame tube. For this reason, the regularities of convective heat transfer in the heating zone will not be taken into account for simulation the heating dynamics along the fuel gas control channel.

As opposed to the fuel gas, the emulsion flow supplying the preheater performs is heated through the convective heat transfer exchange, i.e. mixing with the already warmed-up emulsion layers. The direct contact of the input streams with the flame tubes is constructively excluded. As a result, the mixing intensity factors, estimated by the period of time of the particles in the plant, acquire additional significance.

Taking into account the short analysis of the technological process of the emulsion heating and recommendations [8, 9], the dynamics of the oil-gas separator along the emulsion heating channel will be realized as a sequence of aperiodic dynamic elements of the first order.

4. Simulation model of the control plant (oil-gas separator)

The value of the target parameter namely the temperature of the crude oil emulsion at the output of the heating section is determined from the equation:

\[
t_{\text{em\_out}} = t_{\text{em\_in}} + \frac{0.01 \cdot V_{\text{gas\_real}} \cdot \eta \cdot \text{REL}_{\text{caloric}}}{G_{\text{em\_real}} \cdot C_{\text{em}}}.\]

The following input signals support to the simulation model:

- Volume flow of fuel gas in the heating section \( V_{\text{gas\_real}}, \text{m}^3/\text{h}; \)
- Mass consumption of oil emulsion in the heating section \( G_{\text{em\_real}}, \text{t/h}; \)
- Temperature of oil emulsion on the input to the heating section \( t_{\text{em\_in}} \) (Твх), °C;
- Relative calorific value of fuel gas \( \text{Rel}_{\text{caloric}}, \text{MJ/m}^3; \)
- Heat capacity of the oil emulsion \( C_{\text{em}} \) is the, MJ/t °C.

The following output signals of the model:

- Temperature of the crude oil emulsion on the output of the preheating section, \( t_{\text{em\_out}}, \text{°C}; \)
Efficiency $\eta$.

The dynamics of the control object (Figure 1) is described by aperiodic links of the first order with the following parameters:

- The thermal inertia of the walls of the flame tubes on the fuel gas line is taken into account by the time constant $T_{\text{time\_gas}}$;
- The convective heat transfer during the mixing of the emulsion at the input to the heating section on the oil emulsion line is determined by the time constant $T_{\text{time\_em\_in}}$;
- The convective heat exchange at the output of the heating section on the line of the heated oil emulsion is set by the time constant $T_{\text{time\_em\_out}}$.

Numerical values of the listed parameters of dynamic elements are determined based on expert estimates.

5. Single-loop control system of the emulsion temperature

Using a simulation model of the control object, a single-loop control system for controlling the emulsion temperature at the output of the oil-gas separator was developed (Fig. 3). The input signal of the PI controller is the mismatch error signal between the set value of the heat flow $\text{Ratio\_set}$ and its current value $\text{Ratio\_Egas/Eem}$. The signal from the output of the PI controller namely the volume flow of fuel gas in the heating section $V_{\text{gas\_in}}$ is supplied to the subsystem $\text{Subs\_Heater\_plus\_Egas/Eem}$, which simulates the control object.
The developed single-loop control system for regulating the ratio of heat flows has to stabilize the temperature of the oil emulsion. So for checking proposed regulating scheme the typical scenarios for the technological process were used namely the change in flow rate (Fig. 4a) and the hydrometric content of the emulsion (Fig. 4b).

To the next step the efficiency of the proposed single-loop control system was evaluated. For the simulating low-frequency uncontrolled fluctuations in the temperature of the oil emulsion a sinusoidal signal was supplied to the input of the model (Fig. 5).
In accordance with the test results (Figure 4), proposed ratio regulator successfully compensates the random step changes in the flow rate and hydrometric content of the emulsion and provides a stable aperiodic transient at the output of the plant. While uncontrolled disturbances namely fluctuations in the temperature of the oil emulsion were uncompensated and an unstable oscillation transient is observed at the output of the control system (Fig. 5). Thus, in order to provide the required control quality, the temperature of the oil emulsion at the output of the oil-gas separator has to control by using an additional regulator.

6. Two-loops cascade control system of the oil emulsion temperature

In order to improve the control quality of the oil-gas separator, the author [10] offered stabilizing the ration of flows with correction to the target parameter of the control object [10]. In contrast to the traditional regulating scheme of the crude oil emulsion temperature in the heating section of the plant, we propose to stabilize a ratio of the virtual values. The leading control channel in this system is set a ratio which is connected with the heat flow necessary for the emulsion heating. The slave control channel is minimized the unbalanced signal regulating the heat flow associating with the supply rate of the fuel gas.

The functional diagram of the advanced process control system for regulating the crude oil temperature $T_{\text{em\_out}}$ in the oil-gas separator is shown in Fig. 6. In the discussed system the main perturbation influences are the change in the composition and density of the fuel gas, the fluctuations in the flow rate and the hydrometric content of the emulsion. Data is transmitted through two control channels, namely the calorific value of the gas and the heat content of the emulsion. And then the control system compensates the listed perturbation influences. The errors of virtual analyzers and uncontrolled disturbances for example, daily fluctuations associated with changes in ambient temperature, are taken into account by the main regulator.

![Figure 6. Advanced process control system structure](image-url)

To stabilize the ratio $R_{\text{Egas/Eem}}$, the main controlled perturbations such as the rate flow and hydrometric content of the emulsion, and also the gas density should not affect the emulsion temperature at the output of the oil-gas separator. If, due to an uncontrolled change in the thermal characteristics of the plant, the output variable $T_{\text{em\_out}}$ is deviated from the set value $T_{\text{em\_set}}$, the main controller automatically connects to the control process and changes the set point $\text{Ratio\_set}$.

To exclude the "rocking" of the proposed cascade control system, it is necessary to prohibit the simultaneous start-up of regulators during the simulation. When the oil-gas separator control system starts up, the ratio controller operates the process to the set point given by the master controller. To realize this requirement, a different sampling time for master and slave regulators was used in the simulation model of the control object (Fig. 7).
Figure 7. Model of the two-loop cascade control system in Matlab

The study of the two-loop cascade control system was performed under fluctuations in the gas volume flow (Fig. 7a), and also under simultaneous action of controlled high-frequency and uncontrolled low-frequency perturbations, namely the flow rate and the input emulsion temperature (Fig. 7b).

Figure 8. Results of analysis the regulation the crude oil emulsion through the two-loop cascade control system

The obtained diagrams confirm the effectiveness of the proposed method for the regulation of the oil emulsion temperature. According to the diagram in fig. 8a, the low-frequency uncontrolled perturbation is almost completely eliminated by the master controller through correction of the set point to the slave controller. If the high-frequency and low-frequency perturbations actions simultaneously as shown in fig. 8b, the oil emulsion temperature will be stabilized with a sufficient accuracy at a given set point.

Conclusion
The proposed simulation model of the advanced process control system for regulation the oil emulsion temperature at the output of the oil-gas separator includes in the following elements:

1. The virtual analyzers for calculating the qualitative indicators of input flows, namely the total heating value of the fuel gas flow; the heat content (amount of heat consumed) of the oil emulsion and also the ratio of these parameters.

2. The slave regulator controls the ratio between the total heating value of the fuel gas flow and the amount of heat necessary to heat the emulsion to a given temperature. The output signal from this regulator operates the valve installed on the fuel gas pipeline.
3. The master regulator generates a set point for the slave regulator. The proposed advanced process control system is intended for the two-loop cascade regulation the oil emulsion heat through the ratio of heat flows. The adequacy of the described above solutions has been verified through the simulations in the Matlab software. The maximum effect is achieved under the condition that perturbations affecting the master regulator will appear much less frequently than disturbances of the slave regulator. For example, diurnal fluctuations in the thermal characteristics of the oil-gas separator are taken place more rarely than the hourly pulsations of the load of the emulsion discharge. The settings of the master and slave regulators should be selected in such a way that the upper regulator "does not swing" the lower one.

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