INTERNATIONAL JOURNAL ON ORANGE TECHNOLOGY

https://journals.researchparks.org/index.php/IJOT e-ISSN: 2615-8140|p-ISSN: 2615-7071

Volume: 03 Issue: 6 |Jun 2021

AUTOMATIC REGULATION SYSTEM FOR SULFUR PURIFICATION OF NATURAL GAS

Sevinov J. U

Tashkent State Technical University, Tashkent, Uzbekistan

Ashuraliyev A. A.

Tashkent State Technical University, Tashkent, Uzbekistan

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***Abstract**:* Algorithms for the synthesis of a fuzzy system for automatic control of natural gas desulfurization processes are presented. When forming the problem of analytical design of the regulator to control the temperature of the upper part of the column, the method of the minimum of the integral quality criterion was used. The presented results of mathematical and computer modeling showed that the designed optimal combined system can provide the required quality of the column temperature control process. The model parameters were estimated using the recursive filtering identification algorithm modified for the multidimensional case. In this case, the synthesis of a control algorithm consists of determining a control strategy that minimizes the variance of the controlled coordinate. The results of numerical analysis have confirmed their effectiveness, which makes it possible to use them in solving applied problems of optimizing the parameters of a combined fuzzy control system for the process of desulfurization of natural gas.

Keywords: fuzzy system, control object, parameter optimization, method of minimum integral quality criterion, regularization

I. Introduction

The intensification of production processes is directly based on modern methods of automatic and automated control. The use of these methods is largely associated with the use of computers to solve modeling problems in order to both better study the production process and determine, in a sense, optimal control actions that increase the efficiency of the object's functioning. Both of these tasks are closely related, and as knowledge increases and the patterns of functioning of the production process become more precise, conditions are created for finding such an impact on the object that provides the best results [1-14].

In the presence of disturbances at the inlet of the installation (composition, flow rate, physicochemical properties of the initial gas mixture and absorbent), as well as deviations (temperature and pressure in the apparatus), deviations of the quality characteristics of the purified gas from the required values are possible. To determine these deviations, it is advisable to use a system for regulating the degree of extraction by changing the flow rate of the absorbent and its temperature.

Formulation Of Ohe Problem

In order to maintain the temperature of the absorbent in A-1, it is sent to water coolers, in which it is cooled due to the transfer of heat through the surface of the walls to the cold heat carrier. The required amount of refrigerant V is determined by calculating the heat load on the refrigerator [5,6,9,10]:

$$V = \frac{Q_T}{c^x(t_{x.k} - t_{x.н})} = \frac{L_н c^a (t_{ж} - t_{ж.н})}{c^x(t_{x.к} - t_{x.н})},$$

where Q_T – the heat load on the refrigerator (kW); c^a, c^x – mass heat capacities of the absorbent and refrigerant at average temperature (kJ/(kg K)); $t_{ж}$, $t_{ж.н}$ – the initial temperature (at the inlet of the refrigerator) and the final temperature (at the inlet of the absorber) of the absorbent; $t_{x.k}$, $t_{x.н}$ – final and initial temperatures of the refrigerantю.

II. Main part

Under these conditions, the system under development must provide dynamic accuracy in terms of temperatures: from the upper part of the column $A1$ to +2°C. The regulation time of all the above temperatures should not exceed 2.5 minutes.

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Existing deviations from technical conditions can lead to a deterioration in the quality of gas purification.

Figure 1 shows a system for controlling the temperature and flow rate of the reagent, using a fuzzy controller KIR-1 (FR) and KIR-2 (PID).

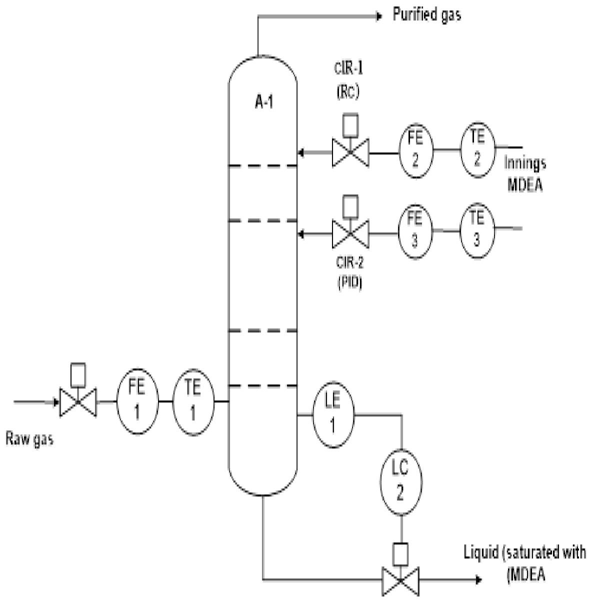

Fig. 1. Control system for temperature and reagent consumption

with a fuzzy controller KIR-1 (RC) and KIR-2 (PID).

An analysis of the operation of a natural desulfurization unit showed that the existing local automatic control systems built on the basis of traditional regulators do not allow obtaining the required quality of process control. One of the effective ways to solve the problem of synthesis of control systems is the analytical design of controllers. Taking into account the above, the problem of analytical design of a regulator for controlling the temperature of the upper part of column *A1* is formulated as follows: it is required to find the control law:

$$u(t) = \varphi(x, \dot{x}, \ddot{x}), \quad (1)$$

transferring the system from the initial state

$$x_o = x(0) = 10^\circ C\,;\; x_o = x(0) = 10^\circ C\,;\; \ddot{x} = \ddot{x}(0) = 0, \quad (2)$$

in the end

$$x(T) = x(T) = \ddot{x} = \ddot{x}(T) = 0, \quad (3)$$

at $T \to \infty$, providing a minimum of the integral quality criterion

$$Y(x, u, \Theta) = \int_0^\infty (x^2(t) + \Theta u^2(t))dt \to \min, \quad (4)$$

with control restrictions

$$|u(t) \le U_{\max}|, \quad (5)$$

where Θ is a constant coefficient; $U_{\max} = 300 м^3 / час$

Gradient controller equations

For ease of indexing, x_1 and u_1 will simply denote x and u.

The posed problem of synthesis of the optimal control (1) - (3) can be solved analytically using the maximum principle [3,9,10,15,16] at fixed values of Θ in (4). Before solving the problem of synthesis of optimal control, it is necessary to bring equations (2) to the normal form of the system of differential equations:

$$x_r(t) = F_r(x_1, x_2, x_3, u) = \sum_{j=1}^{n=3} d_{rj} x_j(t) + c_r u(t), \; r = \overline{1,3}. \quad (6)$$

Having compiled a system of auxiliary differential equations

$$\dot{\psi}_0(t) = 0; \dot{\psi}_0(t) = -\sum_{i=1}^{n=3} \psi_i(t) \frac{\partial F_i(x_1, x_2, x_3)}{\partial x_j}, \; j = \overline{1,3}, \quad (7)$$

and defining the Hamiltonian function at $\dot{\psi}_0 = -1$ [2,3,16]:

$$H(x_0; x_1, \ldots x_3, u, t) = -\left(x_1^2(t) + \theta u^2(t)\right) + \sum_{r=1}^{n=3} \psi_r(t) \left[\sum_{j=1}^{n=3} d_{rj} x_j(t) + C_r u(t)\right], \quad (8)$$

find the linear part of the control law.

From the necessary condition for the maximum of function $H(x_0, x_1, x_2, u)$, i.e. $H(x_0, x_1, x_2, u)$, we obtain the following control law:

$$u(t) = (2\theta)^{-1} \sum_{r=2}^{n=3} C_r \psi_r(t). \quad (9)$$

It follows from (5), (9) that control law $u(t)$, which ensures the maximum value of the Hamiltonian, will be a linear function with saturation. To determine the linear part of the control law depending on the phase coordinates of system $x_r(t)(r = \overline{1,3})$, it is necessary to establish dependence $\psi_r = g_r(t)(x_1, x_2, x_3)$.

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Therefore, adding to the conjugate system of differential equations (8) the equation of the object (1) taking into account (9), we solve the system $2n=6$ differential equations:

$$\dot{x}_r(t)=\sum_{r=1}^{n=3} d_{rj}x_j(t)+(2\theta)^{-1}\sum_{r=2}^{n=3} C_rC_j\psi_j(t);$$

$$\psi_j=\partial F_0/\partial x_r-\sum_{r=1}^{n=3}\psi_j(t)\partial F_j/\partial x_r;$$

(10)

$$r=\overline{1,3},\ \text{at}\ \left|(2\theta)^{-1}-\sum_{r=1}^{n=3} C_j\psi_j(t)\right|\le U_{\max};$$

or in expanded form:

$$\dot{x}_2(t)=\dot{x}_1(t)-24{,}84\dot{x}_2(t)+21{,}706\dot{x}_3(t)+\theta^{-1}(622{,}39\psi_2(t)+679{,}4046\psi_2(t));$$

$$\dot{x}_3(t)=-21{,}706x_2(t)+18{,}39x_3(t)+\theta^{-1}(679{,}4046\psi_3(t)+741{,}7026\psi_3(t));$$

(11)

$$\dot{\psi}_1(t)=2x_1(t)-\dot{\psi}_2(t);\dot{\psi}_2(t)=-\psi_1(t)+24{,}84\psi_2(t)+21{,}706\psi_3(t);$$

$$\dot{\psi}_3(t)=-21{,}706\dot{\psi}_2(t)-18{,}39\psi_3(t).$$

The equation of system (11) takes the form:

$$\alpha^6-14{,}9168\alpha^4+(1244{,}678^{-1}-59{,}20)\alpha^2-35454^{-1}=0.$$

(12)

As can be seen from Fig. 2, the transient process of controlling the temperature of the upper part of the column (curve 2) proceeds without overshoot with a static error less than 1°S. Deviation of parameters $k_t(i=1)$ from the optimal values leads to a deterioration of the integral quality criterion (curves 1, 3-6).

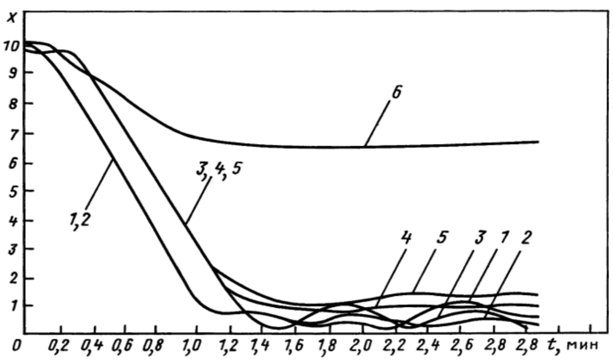

Fig 2 System simulation results

The results of mathematical and computer modeling showed that the designed optimal combined system can provide the required quality of the column temperature control process.

It is expedient to use the current value of raw material consumption for combined stochastic temperature control [17, 18]. All minor disturbances are combined under one disturbance - object noise. With this in mind, the channels for influencing the temperature of the upper part $A1$ through the control, disturbing inputs and the noise channel. We observe the progress of the process using the display. Before the start of the experiment, we determine the permissible limits for changing the regulatory and regulated parameters.

Observing the course of the process, regulating actions are introduced in such a way that the parameters change within acceptable limits, but do not go beyond them.

The experimental results for the temperature of the top of the column are shown in Fig. 3.

The discreteness interval is chosen so that the system will work after implementation.

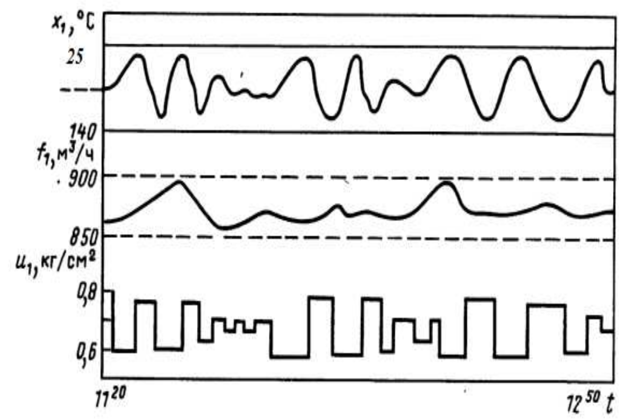

***Fig. 3. Experimental results for the temperature of the upper part of the absorber** $A1$.*

The model parameters are estimated using the recursive filtering identification algorithm modified for the multidimensional case.

The dynamic model obtained in the above described way for the temperature channel of the upper part of the column $A1$ "feed flow rate - the temperature of the upper part of the column K1" and along the noise channel is as follows:

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$$x(nT)=\frac{8{,}51+4{,}28z^{-1}+2{,}26z^{-2}}{1-1.29z^{-1}+0.33z^{-2}}u(nT-2T)+\frac{2{,}72-1{,}11z^{-1}+0{,}76z^{-1}}{1-1{,}29z^{-1}+0{,}33z^{-2}}f(nT-4T)+$$

$$+0{,}12\frac{1-0{,}89z^{-1}+0{,}16z^{-2}}{1-1{,}29z^{-1}+0{,}33z^{-2}}e(nT).$$

(18)

Conclusion

In this case, the synthesis of a control algorithm consists of determining a control strategy that minimizes the variance of the controlled coordinate.

The results of numerical analysis have confirmed their effectiveness, which makes it possible to use them in solving applied problems of optimizing the parameters of a combined fuzzy control system for the process of desulfurization of natural gas.

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