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Mathematical model of forced evaporation in urea production

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The main task of controlling the process of forced evaporation in the production of urea is to maintain a constant concentration of urea in the solution. Indeed, when fed for crystallization, the urea content should be 78%.

The relevance of the development of a control system lies in the need to obtain a function that describes the dependence of the output parameters on the input for further tuning control systems, calculating the parameters of regulators.

The scheme of automation of the forced evaporation process is shown in Figure 1.

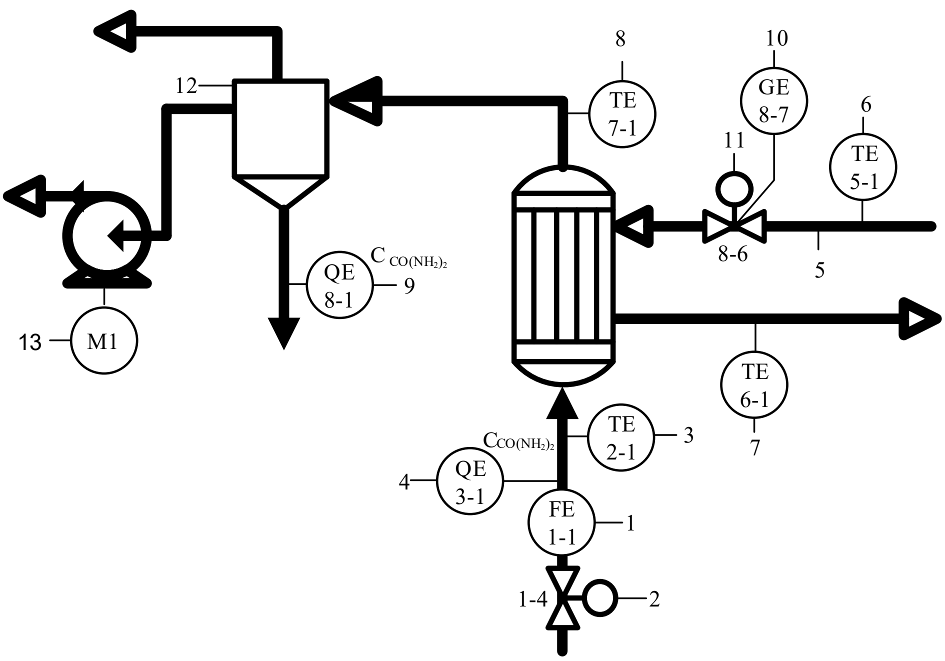

Figure 1. Scheme of automation of the forced evaporation process

Analyzing the automation scheme, we take the flow rate of the hot coolant in the heat exchanger as a control action. We take the initial concentration of urea in the solution as a disturbance. In accordance with this, we have a structural parametric diagram of the forced evaporation process shown in Figure 2.

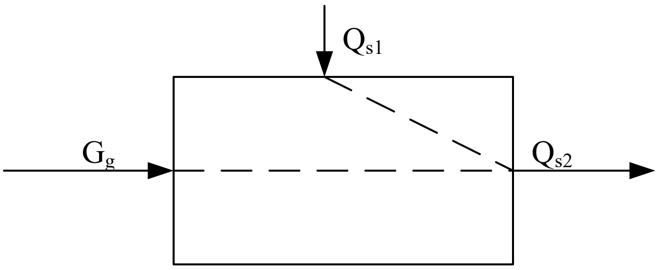

Figure 2. Structural and parametric diagram of the forced evaporation process

In the figure, G_g is the gas flow rate, Q_{s1} is the initial concentration of urea, Q_{s2} is the concentration of urea in the solution at the outlet of the separator.

Let's compose the equation of the dynamics of the forced evaporation process in the production of urea:

$$G_g c_g(\Theta_{g1} - \Theta_{g2}) - KF_1(\Theta_{g2} - \Theta_{s2}) = V_g \rho_g c_g \frac{d\Theta_{g2}}{dt} \quad (1)$$

$$G_{s1} c_{s1} \Theta_{s1} - G_{s2} c_{s2} \Theta_{s2} + KF_1(\Theta_{g2} - \Theta_{s2}) - Wr = V_{s2} \rho_{s2} c_{s2} \frac{d\Theta_{s2}}{dt} \quad (2)$$

$$G_{s1} Q_{s1} - (G_{s1} - W) Q_{s2} = V_{s2} \rho_{s2} \frac{dQ_{s2}}{dt} \quad (3)$$

Variables to be linearized are variables that change during the process, that is Q_{s2}, Θ_{s2} , Θ_{s2} , control variable G_g and disturbance variable Q_{s1}. After linearizing equations (1) - (3) :

$$\frac{V_g \rho_g c_g}{G_g^0 c_g + KF_1} \frac{d\Delta\Theta_{g2}(t)}{dt} + \Delta\Theta_{g2}(t) = \frac{c_g(\Theta_{g1}^0 - \Theta_{g2}^0)}{G_g^0 c_g + KF_1} \Delta G_g(t) + \frac{KF_1}{G_g^0 c_g + KF_1} \Delta\Theta_{s2}(t)$$

(4)

$$\frac{V_{s2} \rho_{s2} c_{s2}}{G_{s2} c_{s2} + KF_1 + r\beta F_2 \xi_1} \frac{d\Delta\Theta_{s2}(t)}{dt} + \Delta\Theta_{s2}(t) = \frac{KF_1}{G_{s2} c_{s2} + KF_1 + r\beta F_2 \xi_1} \Delta\Theta_{g2}(t) \quad (5)$$

$$\frac{V_{s2} \rho_{s2}}{G_{s1} - \beta F_2(\xi_1 \Theta_{s2}^0 - \xi_1 \Theta_п)} \frac{d\Delta Q_{s2}(t)}{dt} + \Delta Q_{s2}(t) = \frac{\beta F_2 \xi_1 Q_{s2}^0}{G_{s1} - \beta F_2(\xi_1 \Theta_{s2}^0 - \xi_1 \Theta_п)} \Delta\Theta_{s2}(t) +$$

$$+ \frac{G_{s1}}{G_{s1} - \beta F_2(\xi_1 \Theta_{s2}^0 - \xi_1 \Theta_v)} \Delta Q_{s1}(t) \quad (6)$$

Or, after the notation, equations (4) - (6) takes the form:

$$T_{11} \frac{d\Delta\Theta_{g2}(t)}{dt} + \Delta\Theta_{g2}(t) = K_{11} \Delta G_g(t) + K_{12} \Delta\Theta_{s2}(t) \quad (7)$$

$$T_{12} \frac{d\Delta\Theta_{s2}(t)}{dt} + \Delta\Theta_{s2}(t) = K_{21} \Delta\Theta_{g2}(t) \quad (8)$$

$$T_{13} \frac{d\Delta Q_{s2}(t)}{dt} + \Delta Q_{s2}(t) = K_{31} \Delta\Theta_{s2}(t) + K_{32} \Delta Q_{s1}(t) \quad (9)$$

Equations (7) - (9) after the Laplace transform:

$$(T_{11}p + 1)\Theta_{g2}(\text{p}) = K_{11}\text{G}_g(p) + K_{12}\Theta_{s2}(p)$$

(10)

$$(T_{12}p + 1)\Theta_{s2}(\text{p}) = K_{21}\Theta_{g2}(p) \qquad (11)$$

$$(T_{13}p + 1)\text{Q}_{s2}(\text{p}) = K_{31}\Theta_{s2}(p) + K_{32}\text{Q}_{s1}(p) \qquad (12)$$

After performing mathematical transformations of equations (10) - (12), we have the final equation:

$$(T_3p + 1)\text{Q}_{s2}(\text{p}) = \frac{K_{11}K_{21}K_{31}}{(T_1p+1)(T_2p+1)-K_{12}K_{21}}\text{G}_g(p) + K_{32}\text{Q}_{s1}(p) \qquad (13)$$

The transfer function was obtained for the control channel "gas flow rate - urea concentration at the outlet of the separator":

$$W(p) = \frac{K}{T_3p^3 + T_2p^2 + T_1p + 1};$$

where :

$$K = \frac{K_{11}K_{21}K_{31}}{1 - K_{12}K_{21}};$$

$$T_3 = \frac{T_{11}T_{12}T_{13}}{1 - K_{12}K_{21}};$$

$$T_2 = \frac{T_{11}T_{12} + T_{11}T_{13} + T_{12}T_{13}}{1 - K_{12}K_{21}}$$

$$T_1 = \frac{T_{11} + T_{12} + T_{13} + K_{12}K_{21}T_{13}}{1 - K_{12}K_{21}}$$

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