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Application of Mixed Control for Determining the Heat Transfer Coefficient of a Heat Exchanger

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Abstract

A bilinear neighborhood model of the station for maintaining the optimum temperature of polyol is considered. Traditional mixed control and control with the use of variable coefficients for the determination of the heat transfer coefficient were carried out, the results obtained were compared.

Keywords: neighborhood model, identification, mixed control, variable coefficients, heat transfer coefficient.

INTRODUCTION

In the production of polyurethane foam, there is a danger of foaming and solidifying of polyol as one of the main components. Polyol solidifies at a temperature of 20°C, so it is necessary to maintain its temperature above this level, which is achieved by the application of optimum temperature maintenance stations at production facilities, the structural model of which is shown in Figure 1.

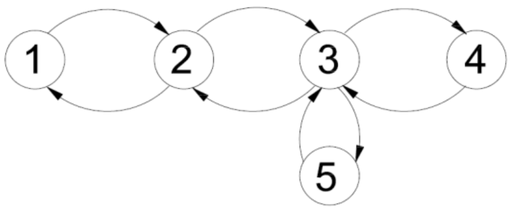

Figure 1: Structural model of a station for maintaining the optimum temperature of polyol

The structural model can be conditionally presented in the form of five main nodes, where 1 is the storage container for polyol, 2 is the polyol pump, 3 is the heat exchanger, 4 is the consumer of polyol, 5 is the refrigerator.

In order to ensure smooth and reliable operation of the station, a heat exchanger should be selected which will provide the required values for the heat transfer coefficient. Typically, in order to determine the appropriate value of the heat transfer coefficient, heat engineering calculation is carried out. This process is quite laborious, because it involves a large number of computational formulas and criterial equations. The application of neighborhood models makes it possible to simplify this process by determining the required value of the heat transfer coefficient as a result of mixed control.

MATHEMATICAL MODEL OF THE STATION FOR MAINTAINING THE OPTIMUM TEMPERATURE OF POLYOL

In order to determine the heat transfer coefficient, a neighborhood model must be constructed. For this case, a bilinear neighborhood model was chosen, where state and control are used as parameters. The bilinear neighborhood model in its general form is written as [1,2]:

$$\sum_{\alpha\in O_x[a]} w_x[a,\alpha]X[\alpha]+\sum_{\beta\in O_v[a]} w_v[a,\beta]V[\beta] + \sum_{\substack{\alpha\in O_x[a]\\ \beta\in O_v[a]}} w_{xv}[a,\alpha,\beta]X[\alpha]V[\beta]=0,$$

where $X[a]$, $V[a]$ – the state and control in the system node; $w_x[a,\alpha]$, $w_v[a,\beta]$ – matrixes of parameters; $w_{xv}[a,\alpha,\beta]$ – block matrix of parameters; $O_x[a]$, $O_v[a]$ – neighborhood of the node a by state and control; $a,\alpha,\beta\in A$, $A=\{a_1,a_2,...,a_n\}$ – finite set of the system's nodes.

The essential state and control components are given in Table 1.

Table 1: State and control components

x[1]	Polyol temperature in storage container, °C
x[2]	Polyol consumption, tons/day
x[3]	Heat transfer coefficient of heat exchanger, W/(m^2·K)
x[4]	Temperature of polyol delivered to consumers, °C
x[5]	Difference between heat carrier temperatures before and after heat exchanger, °C
v[1]	Polyol supply in storage container, tons
v[2]	Pump shaft rotation speed, rpm
v[3]	Polyol temperature after heat exchanger, °C
v[4]	Consumption of polyol delivered to consumers, tons/day
v[5]	Heat carrier consumption, tons/day

The values of the state and control components in accordance with the technological parameters of the operation of the station for maintaining the temperature of polyol are:

x[1]=40 °C, v[1]=22 tons,

x[2]=13.2 tons/day, v[2]=319 rpm,

x[3]=71.2 W/(m²·K), v[3]=22 °C,

x[4]=22 °C, v[4]=11.9 tons/day,

x[5]=5 °C, v[5]=27.5 tons/day.

Following the different order of the input data, they are normalized separately for the state and control components [3,4]:

$$x' = \frac{x - \bar{x}}{\sigma},$$

where x is the normalized value, $\bar{x}$ is the arithmetic average, σ the mean square deviation of values.

In order to carry out identification, it is necessary to specify a part of the model coefficients:

$w_x[1,1]=-1.32065$; $w_v[1,1]=-0.325$;

$w_x[2,2]=-0.50894$; $w_v[2,2]=1.96296$;

$w_x[3,3]=-4.20988$; $w_v[3,3]=-1$;

$w_x[4,4]=-0.25368$; $w_v[1,1]=0.53937$;

$w_x[5,5]=-1.61637$; $w_v[1,1]=0.47534$.

Using the model coefficients obtained as a result of identification, mixed control is performed based on the search for the minimum value of the objective function Z of the neighborhood model [5]:

$$Z = \frac{\sum_{i=1}^{n} |F_i|}{n},$$

where F_i – the left side of the equation of the neighborhood system, n – the number of equations corresponding to the number of nodes in the system.

When carrying out mixed control, the heat balance must be observed:

$$Q = G_{pol} \cdot c_{pol} \cdot \Delta t_{pol} = G_{hc} \cdot c_{hc} \cdot \Delta t_{hc},$$

where Q is the amount of heat, W;

G_{pol} – polyol consumption, kg/s;

c_{pol} – polyol heat capacity, J/(kg·K);

Δt_{pol} – difference between the polyol temperatures before and after the heat exchanger, °C;

G_{hc} – heat carrier consumption, kg/s;

c_{hc} – heat carrier heat capacity, J/(kg·K);

Δt_{hc} – difference between the heat carrier temperatures before and after the heat exchanger, °C.

The heat carrier used is water.

Mixed control was performed in two variants; in the first variant the model coefficients remain constant, while in the second one, mixed control is performed with variable coefficients. The variables are the set coefficients $w_x[1,1]$, $w_x[2,2]$, etc.

RESULTS AND DISCUSSION

The results of determining the heat transfer coefficient in the mixed control process are shown in Figure 2.

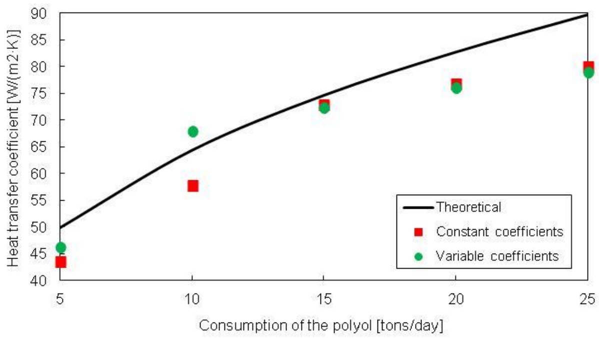

Figure 2: Dependence of the heat transfer coefficient on polyol consumption

Traditional mixed control and mixed control with variable coefficients were compared on the ground of the deviation of the obtained value of the heat transfer coefficient from the theoretical value Δ, and the value of the objective function Z. The results are given in Table 2.

Table 2: Mixed control results

Polyol consumption, tons/day	Δ, %		Z	
	Traditional mixed control	Mixed control with variable coefficients	Traditional mixed control	Mixed control with variable coefficients
5	12.65	7.23	0.3213	0.0111
10	10.11	5.75	0.2351	0.0198
15	2.28	2.95	0.1626	0.0119
20	7.13	8,1	0.6352	0.0372
25	10.93	12.04	1.1206	0.0988

CONCLUSION

Mixed control of the neighborhood model of the station for maintaining the optimum temperature of polyol was conducted in order to determine the heat transfer coefficient of the heat exchanger. The comparison of traditional mixed control and mixed control with variable coefficients was made. Regarding the heat transfer coefficient, mixed controls show results approximately equal in accuracy, not much different from theoretical values. The advantage of mixed control with variable coefficients is the noticeably smaller value of the objective function, which is especially important for system stability [6]. Minor discrepancies in determining the heat transfer coefficient indicate the possibility of using neighborhood models for controlling stations used in the chemical industry.

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REFERENCES

[1] Shmyrin, A.M., Sedykh, I.A., 2010, "Identification and Control Algorithms of Functioning for Neighborhood Systems Based on Petri Nets," Automation and Remote Control, Vol. 71, Iss. 6, pp. 1265-1274.

[2] Blyumin, S.L., Shmyrin, A.M., Shmyrina, O.A., 2006, "Bilinear Neighborhood Systems," Monograph, Lipetsk State Technical University, Lipetsk, Russia (in Russian).

[3] Shmyrin, A.M., Sedykh, I.A., Scherbakov, A.P., Yartsev, A.G., Anikeev, E.S., 2014, "Parametrical Neighborhood Modeling of the Clinker Kiln," Bulletin of Tambov university, Series: Natural and Technical Science, Vol.19, Iss. 3, pp. 927-930 (in Russian).

[4] Shmyrin, A.M., Sedykh, I.A., Shcherbakov, A.P., Yartsev, A.G, 2015, "Two Approaches to the Study of the General Parametric Equation of the Neighborhood Model of the Clinker Kiln," Control Systems and Information Technologies, Iss. 1.1(59), pp. 185-189 (in Russian).

[5] Shmyrin, A.M., Yartsev, A.G., 2017, "Reduction of the Fluctuation Range of Hot-Rolled Strip Coiling Temperature Using Mixed Control with Variable Coefficients," International Journal of Applied Engineering Research, Vol. 12, Iss. 12, pp. 3174-3176.

[6] Shmyrin, A.M., Yartsev, A.G, 2016, "Mixed Control of the Formation Process of the Hot-Rolled Strip Quenching Temperature on the Basis of the Trilinear Neighborhood Model," Information Technologies of Modeling and Control, Iss. 4(100), pp. 290-297 (in Russian).