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THE RESEARCH OF THE BASIC CHANNEL CONTROL PROCESS OF PETROLEUM DISTILLATION AND DEVELOPMENT OF DYNAMIC MODELS

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Abstract. As the object of control, the process of oil distillation in the atmospheric column is complex and multidimensional with interconnected controlled variables. These controlled variables are the outgoing indexes of the column – the quality of receivable hydrocarbon fractions, for assessment of which the boiling point for each product is used. The basic perturbation actions to the process are connected with the adjustment of quantity and the composition of feed stock supplied to the column and flow heat transfer change due to temperature fluctuation of feed stock, temperature fluctuations of external reflux and other factors.

Keywords: oil distillation, dynamic model.

Introduction

The process of oil manufacturing in the column K-102 is the main in the chain of technological processes of an oil refinery. It involves difficult technological processes, which are characterized by continuous mass-exchange, numerous interconnected technological characteristics and an energy output. The control of this process is a hard task for a technologist, leading to different manual management tactics that decrease the efficiency of the process in terms of energy consumption and the quality of the final product (Rasulov *et al.* 1988).

To improve the efficiency of the process aiming to increase the yield of light oil products, it must be managed by the optimal algorithm using a mathematical process model and Computer Engineering. This is also required because of high demands on the quality stabilization of received column fractions, changes in quantity as well as the quality and temperature of raw materials fed into the column. Furthermore, a solution for management of operational tasks is required once targets are changed within the range applicable to the column K-102 as well as the fuel value of selected fractions.

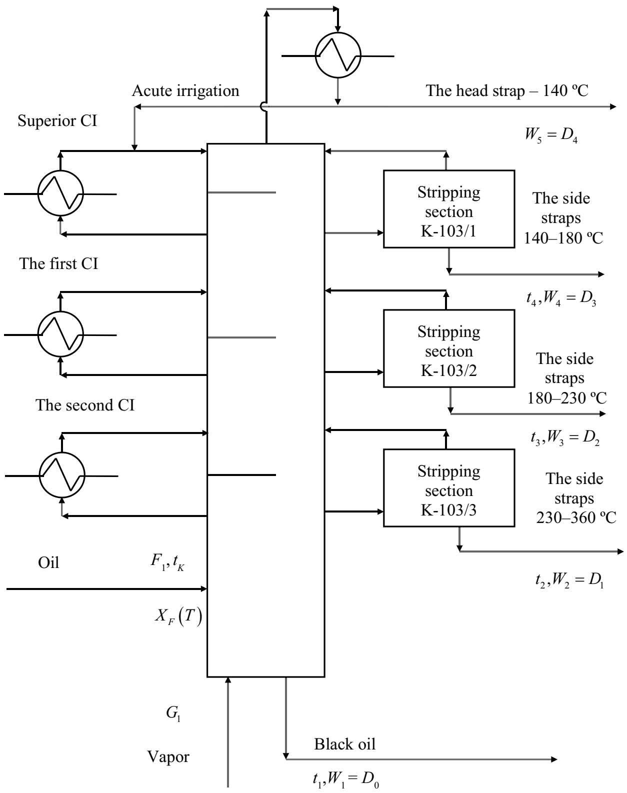

Fig. 1. The design scheme of the column K-102

The design scheme

Consider a column K-102 with the adjacent stripping sections K-103/1, K-103/2 and K-103/3 (Fig. 1). Together with the stripping, the column K-102 represents so-called complex column. In this case, it consists of four simple columns.

Supplying mixture is fed into a simple third column, and then the top product of this column (in the vapour phase) is fed into the second column and etc. Conventionally, each simple column is divided into two sections: the top (reinforcing) and the bottom (exhaustive or stripping) section. Stripping sections of the second, third and fourth columns (due to top-to-bottom design) are made outside of the main column, forming a stripping K-103/1, K-103/2 and K-103/3. The boundaries between the reinforcing sections of simple columns are at the level of circulating irrigation. In Fig. 1, the interface is marked with dashed lines.

The dynamic characteristics of complex systems can be determined analytically, considering the processes occurring in the column. However, this method cannot be practically implemented due to the complexity of processes occurring on *i*-th plate of the distillation column and a large number of complex interrelationships between them.

Dynamic modelling

Under these circumstances, as a distillation column K-102 is an especially complex object, it is useful to empirically define the dynamic characteristics of the entire system. Its great advantage is in the reliability of the obtained characteristics.

This investigated system has *m* input variables and *n* output variables. Between input and output variables there are internal dynamics of communication, the form of which is determined by the corresponding dynamic characteristics.

Denote the dynamic characteristics of the relationship between *i*-th input and *j*-th output transfer function W_{ij}. Then the dynamical system will have $m \times n$ features. They form a characteristic matrix:

$$\mathbf{W}_{ij} = \begin{bmatrix} W_{11} & W_{12} & \cdots & W_{1m} \\ W_{21} & W_{22} & \cdots & W_{2m} \\ \cdots & \cdots & \ddots & \cdots \\ W_{n1} & W_{n2} & \cdots & W_{nm} \end{bmatrix}, \quad (1)$$

The matrix describes all of the dynamic properties of the system.

The block diagram of a dynamical system is shown in Fig. 2. The scheme demonstrates that a change of some output value y_i depends not only on the value of the input x_i but also on other input variables, since they are interconnected. In the experimental study, dynamic characteristic W_{ij} is determined by processing the records of change x_i and y_i over the same period of time.

In this case, the transfer functions W_{ij} are determined by the methods of statistical dynamics according to the normal operation of the facility.

Determining the dynamic characteristics on the basis of the records obtained during the normal operation of the examined object and using the method of correlation functions, the method of moments was used. The moments of the impulse response can be calculated from the correlation functions.

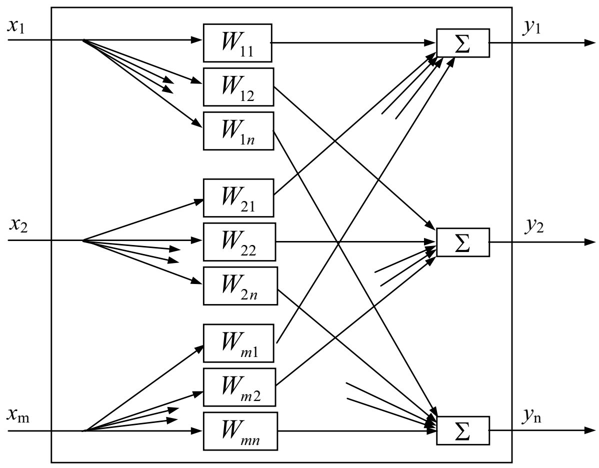

Fig. 2. Block diagram of the dynamical system

For this purpose, experimental data were used on the parameters of the rectification process in the column K-102, obtained by continuous measurements of its parameters within 12 hours in increments of 23 seconds. In case of each parameter of the process, the total number of measurements amounted to 2000.

The quality of target product division, representing the major fractions was as follows: the head strap 140°C, the side straps 140–180°C, the side straps 180–230°C, the side straps 230–360°C and below (vat) product – black oil. Their boiling temperatures were now in the automatic mode. The main control parameters of the column flow rate could be attributed, namely, the acute irrigation, irrigation (u_1), flow rate of the upper circulation (u_2), a circulation flow irrigation (1TSO)(u_3), the second circulation flow irrigation (2nd circular irrigation) (u_4) and the flow rate of water vapour in the column (u_5).

Stripped oil was supplied from the K-101 column, heated to a certain temperature. It was fed into the studied column for two lines of heat transfers. Therefore, consumption of oil (x_3) and its temperature (x_2) were probabilistic quantities and could be attributed to major disturbances. A level of protection could be used in terms of the group of parameters pertaining to the column K-102.

The dynamic characteristics of distillation column control channels could be represented as transfer functions of first order lag of the following form:

$$W_{ij}(p) = \frac{y_{ij}(p)}{x_{ij}(p)} = \frac{k_{ij} e^{-\tau_{ij} p}}{T_{ij} p + 1} \quad \left(i = \overline{1,n};\ j = \overline{1,m}\right), \quad (2)$$

where: $y_{ij}(p)$ – the Laplace transform of the output (adjustable) control channel value; $x_{ij}(p)$ –the value of the

Laplace transformed input (regulatory, disturbing) values; $k_{ij}, \tau_{ij}, T_{ij}$ – respectively, the gain, time delay and time constant of the control channel for *i*-th input and *j*-th output.

According to the method of moments applied by the dependence (2) for any channel:

$$W(p) = \frac{k}{Tp+1} = H_0 - pH_1, \tag{3}$$

where H_0 and H_1 – respectively, the zero and first moments of the impulse characteristics.

At the same time, H_0 corresponds to the gain of the control channel, i.e.

$$k = H_0. \tag{4}$$

From (3) the time constant was calculated:

$$k = (H_0 - pH_1)(Tp+1) = H_0Tp + H_0 - H_1Tp^2 - pH_1. \tag{5}$$

Since the transfer function of first order $H_1Tp^2 = 0$ and $k = H_0$, consequently:

$$T = \frac{H_1}{H_0}. \tag{6}$$

The values H_0 and H_1 for each control channel could be defined using the following formulas:

$$H_0 = \frac{B_0}{A_0} \quad \text{and} \quad H_1 = \frac{B_1}{A_0}, \tag{7}$$

where: A_0 — the time-zero-order correlation function; B_0 and B_1 – respectively, the moments of zero and first order cross-correlation function.

Formulas (5–7) were used to calculate parameters k_{ij} and T_{ij} of the transfer function (3) for all control channels. Thus, the characteristic matrix (1) for the control object was as follows:

$$\mathbf{W}_{ij}(p) = \begin{bmatrix} y_1 & y_2 & y_3 & y_4 & y_5 & \\ \frac{-0.36676}{1.15p+1} & \frac{3.2351}{0.32p+1} & \frac{-2.1917}{1.47p+1} & \frac{-0.49141}{2.23p+1} & \frac{-2.2527}{1.37p+1} & u_1 \\ \frac{0.011556}{0.69p+1} & \frac{-0.18761}{1.88p+1} & \frac{0.016438}{0.68p+1} & \frac{-0.00045435}{2.04p+1} & \frac{0.026436}{3.24p+1} & u_2 \\ \frac{0.0019557}{1.86p+1} & \frac{-0.24339}{1.03p+1} & \frac{-0.027777}{1.9p+1} & \frac{-0.030462}{1.64p+1} & \frac{-0.01529}{2.01p+1} & u_3 \\ \frac{0.010395}{3.74p+1} & \frac{1.9917}{0.67p+1} & \frac{0.10417}{2.31p+1} & \frac{0.16239}{1.05p+1} & \frac{0.10291}{0.8p+1} & u_4 \\ \frac{-0.1793}{2.46p+1} & \frac{-27.858}{0.54p+1} & \frac{-1.3252}{1.08p+1} & \frac{-2.5496}{0.27p+1} & \frac{-1.7112}{2.24p+1} & u_5 \\ \frac{0.012014}{2.65p+1} & \frac{-0.68163}{1.19p+1} & \frac{-0.13121}{0.74p+1} & \frac{-0.1104}{1.14p+1} & \frac{-0.082605}{2.55p+1} & x_1 \\ \frac{0.020679}{1.1p+1} & \frac{9.0532}{0.78p+1} & \frac{1.8705}{2.99p+1} & \frac{1.6276}{1.54p+1} & \frac{1.6168}{2.32p+1} & x_2 \\ \frac{-0.0088143}{5.29p+1} & \frac{-2.8502}{1.15p+1} & \frac{-0.16893}{1.76p+1} & \frac{-0.24814}{1.82p+1} & \frac{-0.18611}{3.05p+1} & x_3 \end{bmatrix}. \tag{8}$$

The matrix transfer function could be defined on any channel control u_i, $x_i - y_j$ at the intersection of the corresponding *i*-th row and *j*-th column of the matrix. To determine the degree of connectedness of the application the multiply-matrix of Bristol was used. The initial matrix of transfer coefficients **G**(0) for the system under study was:

$$\mathbf{G}(0) = \begin{bmatrix} -0.366 & 3.235 & -2.192 & -0.491 & -2.25 \\ 0.012 & -0.188 & 0.0164 & -0.0004 & 0.026 \\ 0.002 & -0.243 & -0.027 & -0.03 & -0.015 \\ 0.01 & 1.992 & 0.1041 & 0.162 & 0.102 \\ -0.179 & -27.8 & -1.325 & -2.54 & -1.712 \end{bmatrix}. \tag{9}$$

To calculate the Bristol matrix **G**(0), it should result in a normalized form so that for all its elements the condition was satisfied:

$$-1 \le \lambda_{ij} \le +1. \tag{10}$$

In this case, the value –1 or +1 must correspond to the largest coefficient of transmission through the control values for value y_i.

The matrix of normalized transmission coefficients was given by:

$$\mathbf{G}(0)_H = \begin{bmatrix} -1 & 0.11613 & -1 & -0.19274 & -1 \\ 0.03151 & -0.0067347 & 0.0075003 & -0.0001782 & 0.011735 \\ 0.0053325 & -0.0087368 & -0.012674 & -0.011948 & -0.0067873 \\ 0.028342 & 0.071494 & 0.047528 & 0.06369 & 0.045685 \\ -0.48887 & -1 & -0.60464 & -1 & -0.7596 \end{bmatrix}. \quad (11)$$

A calculation of the matrix of Bristol elements was made:

$$\Lambda = \begin{bmatrix} 1 & 0.0036592 & -0.0053325 & -0.0054625 & 0.48887 \\ 0.0036592 & 4.5356e-005 & -6.5529e-005 & -1.274e-005 & -0.011735 \\ -0.0053325 & -6.5529e-005 & 0.00016062 & -0.00056785 & 0.0041039 \\ -0.0054625 & -1.274e-005 & -0.00056785 & 0.0040565 & -0.045685 \\ 0.48887 & -0.011735 & 0.0041039 & -0.045685 & 0.57699 \end{bmatrix}. \quad (12)$$

Remarks

1. Analysis of the matrix $\mathbf{G}(0)_H$ and Λ shows that it is rather difficult to identify the contours of regulation (i. e., couples $u_i - y_j$) due to especially strong relationship between the variables. Therefore, effective management of such facilities requires strengthening the use of systems management.
2. The solution to all of the above-mentioned problems to determine the statistical and dynamic characteristics of the object was carried out using a specialized software package Matlab and its applications.

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PAGRINDINIŲ NAFTOS DISTILIAVIMO SISTEMOS KANALŲ VALDYMO PROCESŲ TYRIMAS IR DINAMINIŲ MODELIŲ SUDARYMAS

V. Likhavitski

Santrauka

Atmosferinės naftos distiliavimo talpyklos sistemos valdymas yra sudėtingas ir daugiamatis procesas. Jį sudaro tarpusavio ryšiais susieti kintamieji. Tai yra distiliavimo talpyklos parametrai – gautųjų angliavandenilio frakcijų kokybė, pagal kurią nustatoma kiekvieno produkto virimo temperatūra. Šio proceso sudėtingumas siejasi su skysčio, tiekiamo į talpyklą, srauto ir sudėties reguliavimu, srauto temperatūros perdavimo pokyčiais dėl tiekiamo skysčio temperatūros bei atgalinio srauto temperatūros svyravimo ir kitų veiksnių.

Reikšminiai žodžiai: naftos distiliavimas, dinaminis modelis.