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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

OPTIMAL DISTRIBUTION OF PRODUCTIVE CAPACITY OF CONTINUOUS PROCESSES (ON THE EXAMPLE OF HYDROTREATING OF OIL) FOR THE GIVEN PERIOD OF PLANNING

Speciality: 3338.01 – System analysis, control and information processing

Field of science: Technical sciences

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GENERAL CHARACTERISTICS OF THE WORK

Rationale of the work. A great majority of technological processes implemented in continuous flow has a characteristic feature that at the expence of current loading of a technological device it was possible to increase quality of production to a large extent. As a rule, this degree of dependence is closely connected with any external factor. Just for this reason there is always a need for compromise between maximum quality and production volume. The search of this compromise puts forward the control of processing power (loading) of productive volume of the device depending on the quality of raw material during the planning period as a scientific technical problem. From the point of view of automatic control theory the stated problem is a stochastic problem and directly covers the problem of finding of optimal control strategy. İt should be noted that in spite of the fact the there is a wide classification of stochastic problems of optimal control, to day wide analysis of scientific literature shows that this problem was not stated.

Object and subject of the study are the continuons production processes with the following features:

- urrent production intensity, i.e the loading of technological installation is the main control effect determining the quality.
- the loading of the technological installation is related to the assignment on the production volume during the planning period.
- the production quality depends on external excitatiry factor.

The oil hydrotreating process that is the leading field of oil refining industry in the investigation just because as an example drawn great attention of this the loading of industrial installation with a raw material has a powerfull effect on the product quality and density of this deterministic connection is greatly dependent on the external effect factor, i.e. on the raw material composition index.

The special aspect of scientific interest in this process is related to the fact that here with periodicity of loadings (harmonic or impulsive) a number of effects are likely to exist. These effects supposed in a great majority of continuous material flow mode models show themselves more vividly in oil hydrotreating process.

The goal and objectives of the study.

1. Elaboration of mathematical statement of a stochastic optimal control problem with an integral constraint condition for current loading of the installation on period of planning of control action.
2. Elaboration of the solution method of the problem.
3. Simulation of hydrotreating process as a sample object, development of a quality function and solution of the optimal control problem with regard to distribution function of disturbing effect.

Investigation method: The research was implemented according to statistic analysis, mathematical simulation, parametric identification based on statistical data, computer experiments, imitation modelling methodologies.

The clauses to be defended.

1. Calculation of optimal feedback function to determine optimal loading strategy that meet the accessibility criteria for quality optimality, production volume in the ratio of weight factors given with regard to distribution function of extermal effect factor;
2. Imitation model created by generation of random external effect factor of the sought-for optimal feedback function.
3. A control strategy providing high quality and production assignment on a quarter on the example of hydrotreating of petroleum oils in continuous flow.
4. Illustration of optimality indicators of periodically changing loading modes of hydrotreating process.

Novelty of the study are the followings:

1. Solving a stochastic control problem with a restriction condition in the form of equality of current productive capacity on the period of planning of production volume to the integral value with regard to distribution function of disturbance effect.
2. Definition of a feed-back function that provides the problem solution by means of imitation simulation.
3. defining optimal loading strategy under the condition of changes in the quality of raw material as a sample object of hydrotreating processes.

The followings can be indicated as the main arguments

reflecting theoretical and practical importance of the study.

- Gaining economic efficiency in connection with the problem of optimal distribution production volume on the planning period with reghard to disturbing effects in continuous production processes;
- Defining the loading strategy based on distribution function of sulfur content indicator of a raw material in the lubricants hydrotreating processes.

Approbation of the work. The scientific results of the dissertation work were discussed at the following conferences: The II republican conference "Applied problems of mathematics and new information technologies" (Sumgait, 2012); The international scientific conference "Modern scientific technical and applied problems of energy" (Sumgait, 2015); The XIX republican scientific conference of doctoral students and young researchers, devoted to the 70–th jubilee of the NASA (UNEC, 2015), two papers in the international conference "The X international conference on management science and engineering management" (Proc. of the conference the series of advances in intelligent systems and computing) held in Baku, in 2016; The republican scientific conference "Actual problems of applied mathematics" devoted to the 100-th jubilee of the honoured scientist, acad of ANAS, dostor of physico-mathematical sciences, prof. M.L.Rasulov (Sheki, 2016), Abstracts of the 7th İnternational conference on Control and Optimization with İndustrial Applications (Baku 2020), The 3rd International Conference on Mathematical Advances and its Applications (Istanbul I Turkey, 2020).

Applicants personal contribution: All the scientific results is the result of applicants activity or application of supervisors idea direction and problems principal statement to the specific study object.

Author's scientific publications:On the dissertation work 21 scientific papers and conference materials were published, 13 of them are papers, 8 conference materials. 2 of conference materials were published abroad within the collection of Springer publishing hourse. In total the number of scientific publication in **Web of Science** İndex papers in 5.

Name of the organization where the dissertation work is performed: Sumgait State University

The total volume of the dissertation with a sign, indicating the volume of the structural units of the dissertation separately: The total volume of the dissertation-224000 signs (title, contents and introduction-16000 sign, the first is of 16000 sign, the second is of 46000 sign, the third is of 102000 sign, the fourth is of 44000 sign). The work consists of introduction, four chapters, results, 98 references, 5 supplements. The work contains 131 page text, 36 figures and 3 tables.

CONTENTS OF THE WORK

In the introduction the principal difference of determination of control strategy of current productive capacity in processes implemented in continuous flow based on distribution function of external action factor from parametric optimization problems is discussed. It is noted that the existence of the production aasignment on the given planning period makes necessary to consider the problem as a stochastic control problem It is noted that the existence of the disturbing action factor makes necessary to take into account the distribution function as the main statistic characteristics of random variables.

In chapter I the review of scientific references in the field of terminal criteria optimization problems of continuous production processes is given. It is shown that in the systems of automated control of production processes, the control problem in great majority of cases is of static optimization character in continuous technological processes. i.e. the continuous process in the condition of constant flow rate is described by static dependences. Many-dimensioanl regression equations are successfully used for mathematical descripton of such technological processes.

The main result derived from the analysis of scientific literature is that a stochastic optimization problem with a restriction condition stated in the form of equality of integral value of control on the given planning period was not stated or discussed.

Alongside with this it was shown that in the dissertation work in the practice of simulation and optimal control of hydrotreating processes used as a sample object, the static approach dominates. Under the condition when the quality indicators of the raw material are variable, the problem of determination of optimal loading strategy of hydrotreating installation has not found its reflection in scientific literature. Based on the results derived from the analysis of scientific literature, in the dissertation work the scope of problems to be solved, was determined

Chapter II is devoted to the mathemtical statement of the problem of determination optimal loading strategy dependent on external actions of continuous production processes and eloboration of the solution method.

Let us give some notations related to external influence factor, planning period and loading strategy in the practice of control of contoinuous production processes:

-Production volume - $g(t); \quad t \in (0,T];$

-Current production capacity (in the considered problem a control parameter) -$u(t) = \frac{d}{dt} g(t);$ $u \in U$;

-Planning period $(0,T]$;$t \in (0,T]$;

-Production assignment $G = g(T)$; the integral exists for production assignment $G = g(T) = \int_0^T u(t)dt$.

Mathematical statement of the problem.

Assume that there exists the following function associating the production quality with external disturbing effect and control parameter in any continuous production processes:

$$F = F(x,u),$$

where x is a disturbing effect and it is considered that the distributing function for it is known, i.e. the distribution function $y = \varphi(x)$ determined in the interval $0 < x < \infty$ is one of the data in the problem. On the other hand, for the control function u (current loading of the device) the domain $u \in U$ and total production volume accessibility criteria at the time moment T being the end of the plannig period, are the given criteria.

On the other hand, the disturbing effect changes depending on time and arbitrary $x(t), t \in (0,T]$ realization of this random function causes formation of realization $u(t)$. It is accepted that there exists a control body (automate or a man) and that directly associates $u(t)$-realization with $x(t)$ realization according to the maximality condition of the quality $F(x,u)$. That is why, at arbitrary moment $t \in (0,T]$ the function $u(t) = \arg\max\limits_{\tilde{u} \in U} F[x(t), \tilde{u}]$ is defined and so, appropriate realization $u(t)$ is found. It is accepted that the interval $(0,T]$ is rather wide and the ratio T/τ is a rather large number. There $\tau -$ is the damping period of autocorrelation function of a random external effect quantity, i.e. it is accepted that the rather large observation period can justify statistical approach to the problem.

It is reguired: to determine such a control strategy corresponding to the given distribution function $y = \varphi(x)$ that the empiric mathematical expectation on the interval $(0,T]$ of the guality index gets its maximum value. So, we accept the quality criterion as mathematical expectation

$$E[F(x,u)] \to \max \tag{1}$$

The main indication characterizing the problem is that on the interval $t \in (0,T]$ for the control function the following equality type integral restriction condition should be expected:

$$\int_0^T u(t)dt = G \tag{2}$$

Here $G -$ being a production assignment, a constant quantity at the end of the period T expresses the production volume. Here the expression (2) plays the role of accessibility criterion for the problem under consideration. It is clear that in the problem with participation of both quality and accessibility criteria the weight coefficients of these criteria also must participate. The coefficient α that expresses weight ratio of optimality and accessibility criteria is also a known quantity as initial data of the problem, $\alpha \in (0,1)$.

Taking into account the above conditions, we can express an optimal control problem as follows:

$$\begin{aligned} &I_1 = E[F(x,u)] \to \max \\ &I_2 = \left[\int_0^T u(t) - G\right]^2 \to \min, \qquad (3) \\ &I = \alpha I_1 - (1-\alpha) I_2 \to \max; \alpha \in (0,1) \end{aligned},$$

where $E[F(x,u)]$ is mathematical expectation of the quality index during period $t \in [0,T]$.

It is obvious that the stated problem (3) is not a static optimization problem, but just is an optimal control problem .

To provide more visibility we pass to discrete time: $t_n, n = 1,2,..,N$; $t_n \in [0,T]$.

Based on the principle of “elimination” of Lagrange restrictions we introduce the following feedback construction:

$$u^{\max}(t_n) = \arg\max_{u \in U} \left[F[\varphi^{-1}(y(t_n)), u] - \lambda(t_n) \left(u - \frac{G - \sum_{i=1}^{n-1} u^{\max}(t_i)\Delta t_i}{T - t_{n-1}} \right)^2 \right]; \qquad (4)$$

Here $u^{\max}(t_n)$ is a productive capacity (control quantity) affording maximum to the function (4) at arbitrary time t_n is an appropriate inverse function (control quantity); $\varphi^{-1}(y(t_n)) = x(t_n)$ -is appopriate inverse function.

We note that the numeration in the fractional part of the second addend expressing accessibility criteria in formula (4) i.e. in the difference $G - \sum_{i=1}^{n-1} u^{\max}(t_i)\Delta t_i$ -expresses the residual part of the production plan t_{n-1}. The denominator, i.e. the difference $(T - t_{n-1})$ is the time to the end of the planning time, the fraction itself, i.e. $\frac{G - \sum_{i=1}^{n-1} u^{\max}(t_i)\Delta t_i}{T - t_{n-1}}$ shows the avarage productive capacity to tbe attained during the period after $t_n -$. In the expression (4) $u \in U -$ is a variational parameter.

Finally, $\lambda(t_n)$ is a sought-for Lagrange function, i.e. a function that controls the feedback depth ith respect to time depending on distribution function of the external effect factor $x(t_n)$. It expresses optimal control strategy.

Taking into account what has been said above, we can express the problem solution as follows: It is required to determine such $\lambda(t_n)$ corresponding to $y = \varphi(x) -$ that the following condition could be fulfilled:

$$I^{opt}\left[\varphi(x)\right] = \max_{\lambda(t)} \left\{ \alpha\, h^{opt} \sum_{n=1}^{N} F[\varphi^{-1}(y), u^{\max}(t_n)]\Delta t_n - \right.$$
$$\left. - (1-\alpha) h^{yet} \left[\sum_{n=1}^{N} u^{\max}(t_n)\Delta t_n - G \right]^2 \right. , \qquad (5)$$

where $\Delta t_n, N$ expresses discretization step with respect to time and the number of divisions of the interval, h^{opt}, h^{nai} – are normalizing factors for reducing the criteria to the same scale.

Thus, by applying some method we must define an optimal function $\lambda^{opt}(t_n)$ such that the values $u^{\max}(t_n)$, $n = \overline{1,N}$ determined in (4) affords maximum to the expression (5).

If we can determine the function $\lambda(t)$ satisfying the indicated conditions, then we can accept the u_n sequence of numbers affording maximum to the expression (4) at an arbitrary point of the interval $t \in [0,T]$ as a statistic approximation of problem (3). Naturally, when the planning period T equals infinity, there appears trivial solution of the problem, i.e. we get $T = \infty, \quad u = G/T$.

So it is seen that the solution of the problem directly depends on the distribution function to which the disturbing effect $x(t)-$ obeys.

Constructing empiric distribution function $\varphi[x(t_n)]-$ of discretely disturbing effect quantity. In practice we usually work with the values of distribution function of surfur content (disturbing effect $x(t)$) of the hydrotreating raw materials in discrete time interval. For estimating the mathematical expectation $E[F(x,u)]$ there arises a need to use the variant of impulse sequence with regard to the fact that the arbitrary variable $x(t)$ is stepwise. An adaptive variant to pass to the discrete variant of analog signals is known from scientific literature and limited statistics condition can provide higher exactness. Just for this reason, in the dissertation work in order to determine empiric distribution function of disturbing effect based on the adaptive method the discrete record of random signal given in the form of variable duration pulses should be used.

As a result this approach applied to calculate the mathematical expectation formed the two-parameter statistic massif:

$$W = \begin{pmatrix} w_{11}\ w_{12}\ ...., w_{1\nu},..., w_{1p} \\ w_{21}\ w_{22}\ ...., w_{2\nu},..., w_{2p} \\ \dots\dots\dots\dots\dots\dots \\ w_{\mu 1}\ w_{\mu 2}\ ...., w_{\mu\nu},..., w_{\mu p} \\ \dots\dots\dots\dots\dots\dots \\ w_{q1}\ w_{q2}\ ...., w_{q\nu},..., w_{qp} \end{pmatrix}$$

The indicated matrix characterizes the falling probability of amplitudes and duration in the sequence of pulses to the intersection of raws and columns. In spite of the fact that there are some approaches to the solution of the problem, i.e. to determination of the Lagrange function, the concrete solution algorithm was structured on imitation model.

The solution of the problem based on imitation model.

The basis of imitation algorithm of the solution of the problem is the random variable generation with distribution function $\varphi(x)$ and the choice of optimal variant $\lambda^{opt}(t_n)$ corresponding to this random sequence by the calculation experiment. According to the generated external effect $x(t_n)$ it is possible to determine the sequence $u(t_n); t_n \in [0, h, 2h, ..., nh, .., T]$ from the expression (4) and then based on the "empiric choice" principle to get the optimal approximation $\lambda^{opt}(t_n)$. Thus, the problem of optimal control of the cirren productivity capacity to be solved by the imitation simulation was stated. The imitation simulation method reguires the synthesis of random numbers generation with the given statistic characteristics.

To create such a generator, at first a generator with uniform distribution function and generating [0,1] numbers in a unique range was taken and then using itç a generator with needed characteristics was synthesized. When programming the problem, the RAND function of standard programs collection of MATLAB was used as a generator of pseudorandom numbers.

For the solution of the variant of discretely disturbing effect of the problem a random signal generator that can realize arbitrary distribution function, was elaborated. The algotihm is based on the use of an inverse function. Inverse function for the given distribution functions was written, the signals of the generator were affected by the transformation operator (nonlinear) and the distribution function of the signals after such transformation was determined. It was determined that the required accuracy of the distribution function of the obtained generator is independent on the accuracy of the standard generator of RAND and completely meets the set reguirements.

Algorithmization of the problem solved based on the impulse generation algorithm on the indicated algorithm, was implemented. In other word, an algorithm for choosing the optimal function $\lambda^{opt}(t) \in L$ from the set of variants in a simple way, was worked out. According to this algorithm, the function $\lambda(t)$ was discretisized at (6x4) points (for the variables t and λ, respectively) and it was accepted that the one variant where the amount of variants equals 7776 is satisfactory. Two variants of the discretisized function $\lambda(t)$ are described in figure 1.

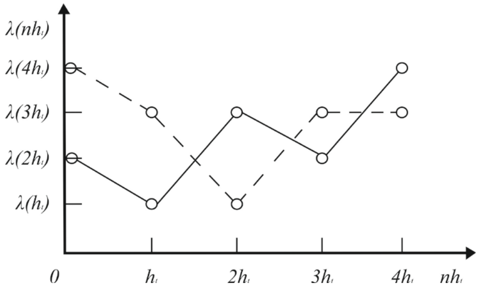


Figure 1. Discretization of the regulating Lagrange function in (6x4) dimension.

Solution of the problem on a simple example. The algorithm developed to determine the sought-for stabilizing Lagrange function $\lambda^{opt}(t)$ on a simple example was verified for the following quality function:

$$F = \frac{1}{(1+x)^{u}}; \quad 0.6 < u < 2; \quad 0 < x < 1; \quad G = 1, T = 1 \qquad (6)$$

Here x is a disturbing effect; u is a control effect and expresses the function with the integral equal to G, on the period T.

The solution of problem (6) by the computational experiment method (based on the simulation princpile) was obtained by dividing the interval $[0,T]$ into 18796 parts. The Gauss normal distribution was taken as a distribution function.

A standard function obeying the distribution principle **randn** was used a generator of random numbers. In 7776 variants obtained as a result of discretization of the function $\lambda(t_n)$, an optimal variant among stabilization functions was determined. This function was shown in figure 2.

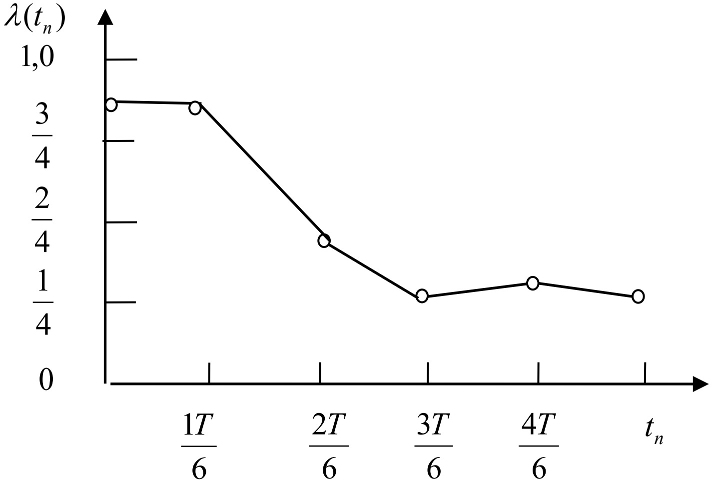


Figure 2. Optimal variant of stabilizing Lagrange function providing the solution of problem (6)taken as a sample.

The best method for comparision of the solution of the sample problem is the analysis of the results obtained by using the functions $\lambda(t_n)=const;$ and $\lambda=\lambda^{opt}(t_n)$. The comparison was made with respect to the best variant of the interval $\lambda(t_n)=\ell;$ where, $\ell\in[0.2;5]$ - ($l=1$ and appropriate loading diagrams (oscillograms) were compared.

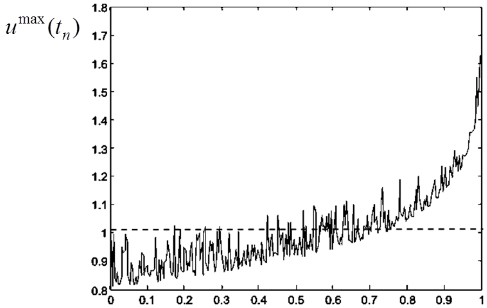


Figure 3.The oscillogram formed by the maximizing control quantity $u^{\max}(t)$ that corresponds to the variant $\lambda(t_n)=1$ under the disturbing effect generated by the **randn** standard generator.

The solution corresponding to the variant $\lambda(t_n)\equiv 1$ is given in figure 3. As can be seen from the figure, if the given ratio of quality and accessibility criteria given at the beginning of the interval can be accepted as optimal, it is observed that approaching the final the index of the control parameter lags far behind G.

As can be seen, this oscillogram explicity shows that the function $u^{\max}(t)$ does not remain constant on the period and to the end of the period this function tends to increase. This effect is related to the fact that the quality function is a decreasing function with respect to the variable u. In other words, the fact that the function $u^{\max}(x)$ is smaller than the empiric mathematical expectation $\frac{G}{T}$ – on the given interval manifests itself, i.e.:

$$\frac{G}{T} - M[u^{\max}(x)] > 0$$

The total efficiency index at the beginning of the interval gives priority to the quality criterion, because the role of the accessibility criterion was not able to rise high enough. As approaching to the end of the interval, because of increase of inclination the feedback amplifies and the mean value of $u(t)$ changes towards ascent .

In figure 4, formation of the process adjusting itself at the expense of the influence of the function $\lambda^{opt}(t)$ was shown. As can be seen, in this case, it is possible to keep the quality and accessibility criteria in the period in the equal ratio. This time, the mean value of $u(t)$ may remain constant in the period.

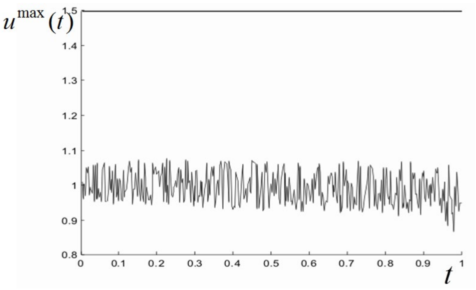


Figure 4. The oscillogram of the function $\lambda = \lambda^{opt}(t)$ when using the function $u^{\max}(t)$ taken as optimal.

Thus, analysis of the problem that we solve as a sample leads to the conclusion that under the disturbing effect, such a stabilizing feedback function $\lambda^{opt}(t)$ should be chosen for optimal distribution of productive capacity put forward on the given planning period that the mathematical expectation $E[u^{\max}(t)]$ calculated with respect to the random function $u^{\max}(t)$ stays constant on the interval $t \in [0,T]$.

The programmed solution of the stated problem by means of the simple choice method reguired 8 minutes (in our computer with mean calculation resources). This time, in the experimental calculation carried out on each planning period, the number of distributing pulses was 2470.

Chapter III was devoted to mathematical simulation of industrial scale hydrotreating process implemented in continuous flow. As it was noted, the goal of mathematical expectation is to determine optimal loading strategy in connection with sulfur content indicator of a raw material. In fig 5, the main technological device of the hydrotreating process, a stationary catalyst layer was shown. In connection with the dissertation work mathematical simulation of only a reactor block was implemented. The simulation was implemented only from the aspect of the stated optimal loading with taking into account some necessary proper features. Under 350-380^{0}C temperature, the sulfur oil is brought together with hydrogen in the fixed layer of the catalyst. Qoing through the absorption, adsorption (dissolution of gases in liguid and solid body media) processes hydrogen creates sulfur gas by means of the catalyst and the causes the raw oil to be desulfurized. As the speeds of the two processes in the reactor are greater for several times than material flow rate, they can meet the criteria conventionally called a grasistationary condition in the scale of reactor model in the from of the system of differential equations and therefore, they fully justify their entrance to the system in the form of static dependence. So, the reactor model can be written in the form of a partial differential equation composed by the concentraction of hydrogen, sulfur compounds and hydrogen sulfur that is a reaction production, in appropriate phases (gas, liguid and solid phases). The length coordinate of the reactor and time are used as independent variables.

Reactor
Hydrogen-containing gas   sulfur oil
Granular catalyst
hydrogen surfide gas: treating or reuse   refined oil
Hydrogen sulful gas

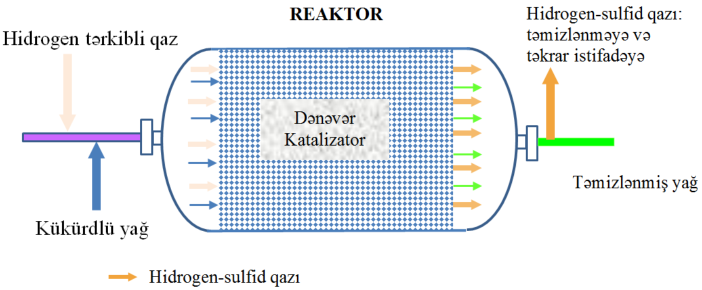


Figure 5. Generalized scheme of oil hydrotreating reactor.

The processes in three phases and exchange between them was given in the schematic form.

Active surface oil catalyst oil phase gas phase active surface of catalyst

Sulfur oil hydrogen containing gas
Hydrogen sulfide containing gas

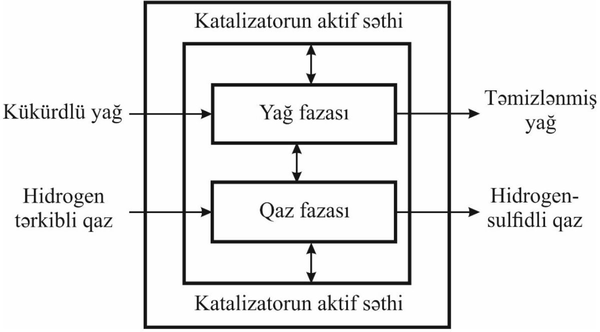


Figure 6. Schematic scheme of mass exchange of lubricants in hydrotreating process.

The gas phase consists of hydrogen and sulfur gas obtained as a result of reaction with it. The oil phase directly consists of the processed oil, the solid phase consists of a catalyst layer. As in the similar processes, ignorance of diffusion is connected with the existence of stationary (fixed) layer in the reactor:

$$\frac{\partial p_i}{\partial t}+\frac{v_q}{\sigma_q\rho_q}\frac{\partial p_i}{\partial x}-w_{qy}\left(\frac{P}{k_i(T)}y_i-p_i\right)=0;\quad i=\overline{1,3};1-H;2-S;3-H_2S$$

$$\frac{\partial y_i}{\partial t}+\frac{v_y}{\sigma_y\rho_y}\frac{\partial y_i}{\partial x}+w_{qy}\left(\frac{P}{k_i(T)}y_i-p_i\right)+w_{yk}^i\left(b_{yk}^i y_i-z_i\right)=0$$

$$\frac{dP}{dx}=\frac{\gamma}{\sigma_k}(v_y+v_q); \tag{7}$$

$$\frac{\partial z_H}{\partial t}-w_{yk}\left(a_{yk}y_H-z_h\right)+2z_H z_S k_0\exp(-E/RT)=0$$

$$\frac{\partial z_S}{\partial t}-w_{yk}\left(a_{yk}y_S-z_S\right)+z_H z_S k_0\exp(-E/RT)=0 \tag{8}$$

$$\frac{\partial z_{H_2S}}{\partial t}-w_{yk}\left(a_{yk}y_{H_2S}-z_{H_2S}\right)=0$$

Initial and boundary conditions:

for $t=0$

$$p_i(x,0)\equiv p_{i0};\quad y_i(x,0)\equiv y_{i0};\quad z_i(x,0)\equiv z_{i0}; \tag{9}$$

$i=\overline{1,3}$; 1-is hydrogen; 2-is sulfur compounds;3-is hydrogen-sulfide.

for $x=0$

$$p_i(0,t)\equiv p_{i0}(t);\quad y_i(0,t)=y_{i0}(t);\quad P(t,0)=P_{gir}(t) \tag{10}$$

In these model equations the following denotations were accepted: $\sigma_q=\frac{S_q}{(1-\sigma_k)S}$ is relative area occupied by gas bubbles in the oil; $\sigma_k=\frac{S_0}{S}$ is a relative area accupied by the catalyist in the oil phase; $\sigma_y=1-\sigma_q$ is a relative area occupied by oil phase; p_H, p_S, p_{H_2S} are partial pressures of hydrogen, sulfur and hydrogen-sulfide; y_H, y_S, y_{H_2S} are concentrations of dissolved hydrogen, sulfur and hydrogen-sulfide in oil phase; z_h, z_S, z_{H_2S} is the relative amount of active centers occupied by hydrogen, sulfur and hydrogen-surfur; v_q is volumetric speed of gas; v_y is volumetric speed of oil; P is pressure in the reactor; S, S_0, S_q are total areas of the cross section the reactor, the area occupied by the catalyst in the cross-section of the reactor and the area in the spaces of the cross-section of the reactor (for oil and gas phases); ρ_q, ρ_y – are densities of gas and oil phases, γ is a resistence factor in filtration flow; w^i_{qy}, w^i_{yk} – are substance transfer rates for gas oil and oil-catalyst phases; $k_i(T) = k^*_i(T - 273) + \varepsilon^*_i; i = \overline{1,3}$ is temperature dependence of oil solubility of hydrogen and hydrogen sulfur; $b^H_{yk}, b^s_{yk}, b^{H_2S}_{yk}$ are absoption factor of hydrogen, sulfur and hydrogen-sulfide from oil medium to catalyst suface; E, R, k_0, T are temperature under which reactor is realized.

Research of non-stationary (dynamic) modes of mathematical model.

For obtaining the change of the rate of raw material or hydrogen-containing gas delivery to the reactor with respect to time as a control parameter, in the model (7)-(11) the appropriate equations were written as follows:

$$\begin{gathered}\frac{\partial p_i}{\partial t} - \frac{v_{q0}\left[1 + u_1 \sin(\omega t)\right]}{S\sigma_q \rho_q}\frac{\partial p_i}{\partial x} - w_{qy}\left(\frac{P}{k_i(T)} y_i - p_i\right) = 0; \quad i = \overline{1,3} \\ \frac{\partial y_i}{\partial t} - \frac{v_{y0}\left[1 + u_2 \sin(\omega t + \varphi)\right]}{S\sigma_y \rho_y}\frac{\partial y_i}{\partial x} + w_{qy}\left(\frac{P}{k_i(T)} y_i - p_i\right) + w^i_{yk}\left(b^i_{yk} y_i - z_i\right) = 0\end{gathered} \qquad (11)$$

where the variables z_i – are determined from the system of equations (8).

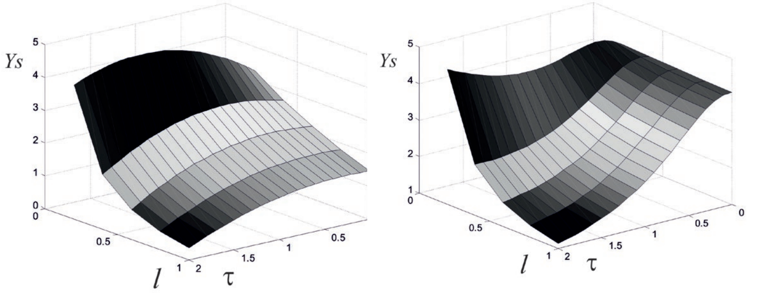
In the changed equations (11) participate additional four variable parameters $u_1, u_2, \omega, \varphi$. These parameters allow to realize sinusoidal control effect on hydrogen containing gas and raw material with the same freguency but with various amplitude and phase shift. The solution algorithm of this problem with numerical methods was developed based on the finite differences method.

The solution algorithm was applied based on the explicit scheme on three point left cornec template with advantages from the point of viw of implementation of a control function.

In figure 7, the change of dynamics of distribution function along the length coordinate of the reactor at the small value of speed of transfer of the raw material to the reactor (a variant in the figure) and at the value greater nan a nominal one (variant b) was given.

As can be seen in the great flow speeds the desulfidazation process can not end and in the exit the amount of sulfur compounds (Y_S) is significantly great. As in the low speeds the period of staying of oil in the catalytic medium the final treating increases. As the speed of flow has influence on chemical processes, this dependence is not proportional and manifests itself in a more complicated form. Thus, complete accordance of the drawn mathematical model with physical sense shows itself explicitly.

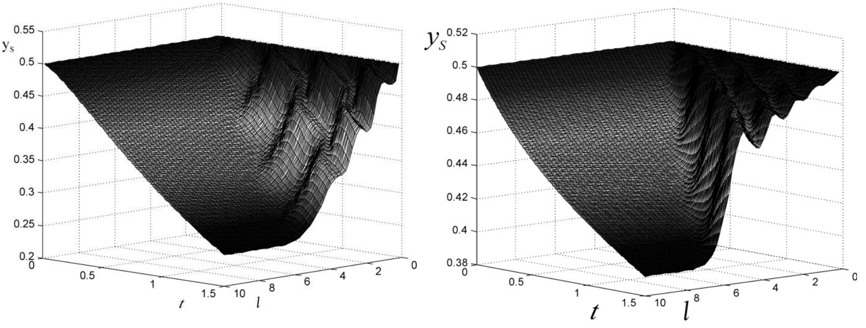
To determine more exactly the drawn mathematical modes, the "active entrance effects" method is used.



a) b)

Figure 7. Distribution of raw materials sulfur-content indicator (ℓ,τ);
a) $u = 0.7$; b) $u = 1.1$

In another characteristics, unlike previous experimantal calculation, the raw material was transferred to the reactor not by constant speed but by periodically changing speed. The non-stationary mode formed when transferring the raw material to the entrance of the reactor by the law $u(t) = \tilde{u}(1 + u_1 \sin \omega t)$ was given in figure 8 -a) and b).



a) b)

Figure 8. Distribution of partial pressure of sulfur compounds along the reactor according to two various non-stationary modes a) $\omega = 2$ rad/min; b) $\omega = 3.5$ rad/min.

As can be seen from the figure, as an initial condition of the model, the sulfur degree (in oil phase) along the reactor was taken as an equidistribution case and was numerically taken equal to 0.5.

Change of sulfur compounds in the oil phase is a gradual process and is of wavy character. The wave propagation along th reactor increases with respect to time and stops about to 5-6 meters of the reactor. The cause of this appearance is only the restriction of the time axis by 1.5 minutes, i.e. discontinuity of the graph at this point.

In fact, this wavy process continues to infinity. In mathematical physics models this process is known as a “travelling wave”.

The main result derived from the study of nonstationary modes of mathematical model .

As a result of numerous calculation experiments it was obviously demonstrated that a nonstationary material flow has a wider optimality factor. Thus, as a result of model study we can draw such a conclusion that at the expense of impulsive transfer of raw material, within stable quality indicators of the process the main indicators of the loading of the reactor may be significantly increased. The lower is loading degree of the reactor, the positive effect obtained from application of impulsive modes is greater.

The result draws attention as a main result obtained from simulation of hydrotreating process on the base of physical-chemical regularities and from implementation of computing experiments. This result in fact is reflected in the graph given in fig. 10.

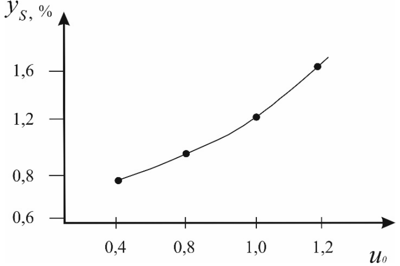


Figure 10. Dependence of hydrotreating indicators ($u(t) = u_0 \cdot (1 + 1.44 \sin 2t), \quad 0 \le t \le 1.5$) on constant addend of speed under harmonically alternating raw material speed condition.

The approiximation of this characteristics gives the following expression:

$$\bar{y}_S = \frac{0.0037}{0.964 + (y_{S0} / y^*_{S0})^{u_0 / v^*_0}}$$

Here, y_{S0}, y^*_{S0} are current and nominal values of sulfur indicators of prossesed carbohydrogens ($y^*_{S0} = 0.5\%$), v_0, u_0^* is a loading indicator of the reactor with respect to a raw material (the volume speed of an average volume speed of raw material in the entrance of the reactor).

This expression is directly used in solving the problem of optimal loading of hydrotreating reactor.

Chapter IV is devoted to algorithmic elaboration of optimal loading to continuous productivity equipments on the example of hydrotreating processes. Here, main attention is directed to two directions: approach to the problem from the aspect of imitation algorithms is to retain stable mathematical expectation of loading during planning period.

Determination of this mathematical expectation to be retained constant in constructing the iteration process and of alternative variants of synthesis of the Lagrange function providing this value to stay constants are discussed.

Creation of iterative calculation process is discussed as one of these approaches and this time the main problem is the determination of the initial point (apoproximation) in the iterative process.

The another approach is the principle of feedback systems, here taking of integral restriction condition into account is searched on the regulating negative feedback principle.

The positive results that could be given on an example of hydrotreating algorithims can directly manifest themselves only swhen solving a specific problem. The model of solution of the hydrotreating processes from the point of view of the posed problem was created on the experimental calculation implemented on differential equations (7)-(10). This model reflects the reaction of the controlled object (efficiency indicator) to the change of the constant addend u_0- of the given speed of the raw material transfer:

$$F = \frac{0.152}{1.81 + 0.89x^{1.6u_0}} + 0.122\, x u_0 \qquad (12)$$

In figure 11 the dependence (12) is given in the graphic form.

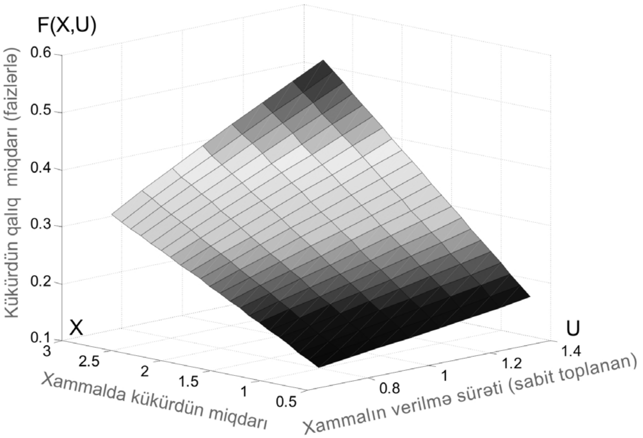


Figure 11. Description of the efficiency function in the domain $0.75 \le x \le 2.85$; $0.7 \le u_0 \le 1.5$.

The solution of the problem was calculated in the variants of the disturbing factor, i.e. in the variant close to the normal distribution of distribution function for the input sulfur of the raw material. The optimal stabilizing Lagrange function was given in figure 12.

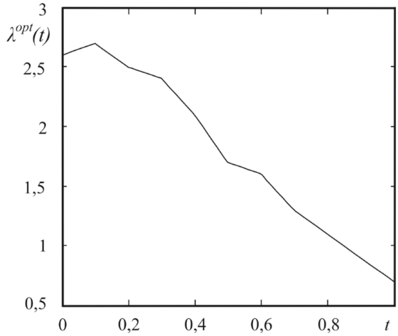


Figure 12. Optimal variants of the regulating Lagrange function.

The main results of the dissertation work

The main results of this dissertation work are the followings:

1. A stochastic optimization problem with equality type integral restriction condition and considering the distribution function of disturbing effect on the control effect was stated. From the point of view of feedback systems, the problem was expressed mathematically. As a result of study it became clear that it is possible to take into account the given distribution function of distrubing effect by chosing an optimal variant of the stabilizing Lagrange function realizing the feedback.
2. An imitation simulation algorithm for determining an optimal feedback function, was offered. Am imitation model was created based on the generation of random external effect factor with the given distribution function and on its base an optimal stabilizing Lagrange function was determined.
3. The posed problem was solved on the example of hydrotreating process of petrolium origin oils and specific results were obtained.
4. The loading of the hydrotreating reactor was implemented in the case of periodic functions and efficiency of non-stationary model was analyzed..

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Personal activity of the applicant in joint works with co-chairs:

[1,2] problem statement (together with coauthors), development of sofware, analysis of results,
[3] solution of e parametric identification problem.
[4,8,12] participation in the setting of the problem, elaboration of the method of empiric distribution functions, compiling the program.

[7] setting the problem (together with coauthors), defining the parameters of mathematical model based on the statistical material. The solution of the Cauchy problem.
[11,13,14] studing dynamical properties of optimal control, software creation.
[15,18] development of solution algorithm of optimal control problem and its solution by means of numerical methods.
[16,19] development of solution algorithm for mathematical model computer solution of parametric identification and optimization.
[20,21] Application of optimal feedback method to the hydrotreating process and its solution.

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