The issue of dynamic optimization of a group of continuous production plants

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Abstract. The article describes the problem of minimizing the consumption of olefins feed, provided that the plan for the production of alkylate for the alkylation process is fulfilled. The basic principles and approaches to the solution of this problem are considered. As a practical application, the method based on interaction with predictive models was chosen. Matlab was used as the environment for development. Mathematical models describing the dynamics of the alkylation process were obtained. The models have high accuracy and can be used to solve the problem of dynamic optimization. A numerical experiment was carried out; the results of the solution were compared with the real historical data of the process and confirmed the efficiency of this solution.

1. Introduction

The key way to increase production efficiency is to optimize the energy balance and reduce the loss of material resources of continuous production (Refinery plant, petrochemical plant, chemical production). This problem can be solved based on the development and implementation of the concept of production management in real-time. Let’s consider continuous production on the example of a refinery. The modern refinery consists of a large number of different types of equipment, technological units, combined into sites and complexes of sites, connected by a technological scheme and combined, ultimately, in the production chain of commercial products. The nature of these links is significantly different: products and intermediates produced at one unit are supplied to the input of other units, heat generated at one production unit is utilized at another, raw materials and energy are distributed among different consumers. The task of optimizing production is not only to maintain the most efficient mode at each plant individually but also to establish between the elements of the technological scheme of communication, ensuring optimal operation of the entire production as a whole.

Currently, management and optimization problems in complex industries (modern refineries) are solved by creating a hierarchical management structure. A graphical representation of the described structure is shown in figure 1 [1]. The current management system of the refinery is a complex multi-level structure. The large dimension of the problem at each level of control, multi-periodicity, and often the complexity and nontriviality of the control problem at each level does not allow applying a single control algorithm. Therefore, the task of building a unified system of tight planning and management can be solved only by applying the decomposition of the General task of management to a set of specific tasks of control, accounting, forecasting, decision-making at each level of production. As a result of decomposition multi-level hierarchical functional structure was obtained. Each top-level task of this structure has a priority of actions concerning the related tasks of the lower level, and the period of
decision-making at the top level more than the lower, and jobs for the lower level are the decisions top-level task [2].

Plantwide optimization is an important element of production management and should be carried out continuously. Moreover, plantwide optimization is a practical solution to the difficulties caused by the high dimensionality of the original problem, the dynamics of the technological object. The search for effective ways to solve this problem is an important direction in the development of continuous production management systems.

2. Problem definition

Consider the problem of optimizing the production of the gasoline component on the example of alkylate. The problem of alkylate maximization based on static mathematical models is described in the article [3]. The next task is to solve the dynamic optimization problem of minimizing the consumption of olefin feed subject to the implementation of the plan for the production of alkylate. The technological scheme is presented in figure 2.
As an optimization function it is proposed to use the formula of deviation from the production plan taking into account the priority factor of products:

\[ p_j \cdot F_{\text{fact}}^j - p_i \cdot (F_{\text{plan}}^i - F_{\text{fact}}^i)^2 \rightarrow \max \]  

(1)

- \( F_{\text{fact}}^j \) – the actual production of olefins feed;
- \( p_j \) – priority factor of olefins feed;
- \( p_i \) – priority factor of alkylate;
- \( F_{\text{plan}}^i \) – the planning production of alkylate;
- \( F_{\text{fact}}^i \) – the actual production of alkylate.

To solve the task of minimizing the consumption of olefin feed subject to the implementation of the alkylate plan of the task it is necessary to solve the following number of problems:
- To determine the methods of solving the problem of dynamic optimization
- Identify mathematical models for solving dynamic optimization and control problems
- Assessment of adequacy of model;
- The solution of a problem of optimization
- Assessment of results of the decision.

3. Theory

The general task of production management must contain all the essential variables in the state of the object, based on which carrying out the synthesis of management. This task in one way or another mathematical decomposition is divided into some interrelated tasks between the two hierarchical levels of management: at the upper level – the level of operational management of production – optimization, and coordination of plants, at the lower level – the management of individual units. In this article, we consider the management of local units. Currently, the following methods are mainly used to solve optimization problems [4-8]: methods of research of functions of classical analysis:

- methods based on the use of undefined Lagrange multipliers;
- dynamic programming;
- maximum principle;
- linear programming;
- convex programming;
- nonlinear programming.

Criterion minimization of consumption of olefins feed is a solution to the problem of nonlinear programming. However, given the various disturbances affecting the process, it is necessary to use a dynamic optimizer, which can act as a mathematical method of model predictive control (MPC). The typical MPC task consists of minimizing the target function \( J \) at each step of calculations \( k \):

\[ J(k) = J_y(k) + J_u(k) \]

where:
\[
J_y(k) = \sum_{j=1}^{n} \sum_{i=0}^{p-1} \left\{ \frac{\omega y_{i,j}}{s_j^y} \left[ r_j(k+i|k) - y_j(k+i|k) \right] \right\}^2
\]

\[P - \text{time horizon;}
\]
\[y_j(k+i|k) - \text{the predicted value of the output } j;\]
\[r_j(k+i|k) - \text{the task to the output } j \text{ at the predicted step } i;\]
\[s_j^y - \text{the scale factor for the output } j;\]
\[\omega y_{i,j} - \text{the weight ratio for the output } j \text{ at the predicted step } i;\]

\[
J_u(k) = \sum_{j=1}^{n} \sum_{i=0}^{p-1} \left\{ \frac{\omega u_{i,j}}{s_j^u} \left[ u_j(k+i|k) - u_{j,\text{arg}r}(k+i|k) \right] \right\}^2
\]

\[u_{j,\text{arg}r}(k+i|k) - \text{setting the manipulated variable } j \text{ at the predicted step } i;\]
\[s_j^u - \text{the scale factor for the manipulated variable } j;\]
\[\omega u_{i,j} - \text{the weight ratio for the manipulated variable } j \text{ at the predicted step } i.\]

To form a mathematical model describing the dynamics of the alkylate production process, it is proposed to identify the process by testing the process responses. Based on the experience of the expert, as well as analyzing the literature, the following matrix of dependencies was formed.

Table 1. Alkylation control matrix.

| Control Variables\Manipulated variables | Olefin feed flow | Isobutane feed flow | Recycle isobutane flow | Fresh acid into the reaction circuit flow |
|----------------------------------------|-----------------|---------------------|------------------------|-----------------------------------------|
| Research octane number of alkylate     | -               | +                   | +                      | +                                       |
| Motor octane number of alkylate        | -               | +                   | +                      | +                                       |
| Alkylate flow                         | +               |                     |                        |                                         |
| End boiling point of alkylate          | +               | -                   | -                      | -                                       |

4. Results of an experiment

The results of the identification of mathematical models and comparison of the model output with the real process are presented below. The models have high accuracy and can be used to solve the optimization problem. As a package for MPC implementation, it is proposed to use Matlab.
Figure 3. Result of model “Alkylate flow”.

Figure 4. Result of model “Research octane number of alkylate”.

Figure 5. Result of model “Motor octane number of alkylate”.

Table 2. Results of models.

|                       | RMSE | MAPE | R   | R^2  |
|-----------------------|------|------|-----|------|
| Research octane number of alkylate | 0.16 | 0.13 | 0.94 | 0.89 |
| Motor octane number of alkylate     | 0.22 | 0.25 | 0.91 | 0.83 |
| Alkylate flow             | 1.49 | 3.18 | 0.97 | 0.94 |
Figure 6. Result of minimizing the consumption of olefin feed subject to the implementation of the plan for the production of alkylate.

To verify the solution of the optimization problem, a comparison is made with the real technological process based on the baseline. Figure 6 shows the solution of the optimization problem at different product weights, as well as the planned task for the production of alkylate. The developed models and algorithms allow us to solve the problem of dynamic optimization minimizing the consumption of olefin feed subject to the implementation of the plan for the production of alkylate.

5. Conclusions
A practical solution of the complete complex optimization problems in real-time refinery difficulties, which are caused by the high dimensionality of the original problem, the dynamics, and inertia of the technological object, was obtained. The search for effective ways to solve this problem is an actual direction of the development of oil refining production. In the traditional approach, static analytical process models are used. Based on these models the target stationary values of key parameters of technological processes along the production chain are calculated. Target values are specified at each calculation step. To achieve a stationary state, the chain of plants may require several tens of hours, provided that there are no significant disturbances in the form of changes in the composition of raw materials, etc., which is often impossible. In this regard, it is advisable to use dynamic models of the process presented in this paper, which are devoid of a significant number of disadvantages inherent in stationary models.

As a result of the study, the principles and approaches to solving problems of dynamic optimization are considered. A method based on MPC is proposed and tested. The optimization criterion is the task of minimizing the consumption of olefins feed subject to the implementation of the plan for the production of alkylate. To solve it, the priority factor of production is used.

The identification of mathematical models was used to describe the dynamics of the process. The models have shown high accuracy and can be used to solve the optimization problem.

The results of the numerical experiment of solving the optimization problem in comparison with the data of the technological process are obtained. The results showed changes in the target optimization function depending on the product priorities, thus the presented method allows solving the required problem.

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