DOI 10.37539/2949-1991.2026.37.2.021
УДК 66.069

Меликов Эльчин Адил, доцент,
Азербайджанский Государственный Университет
Нефти и Промышленности
Melikov Elchin Adil, associate professor,
Azerbaijan State University of Oil and Industry

Гулузаде Байрам Эльчин, мастер,
Азербайджанский Государственный Университет
Нефти и Промышленности
Guluzade Bayram Elchin, master,
Azerbaijan State University of Oil and Industry

ОПТИМАЛЬНОЕ УПРАВЛЕНИЕ ПРОЦЕССОМ ПОЛУЧЕНИЯ ПРОПИЛЕНА В ПРОИЗВОДСТВЕ ЭП-300
OPTIMAL CONTROL OF THE PROPYLENE PRODUCTION PROCESS IN THE EP-300

Аннотация. В статье рассматриваются вопросы оптимального управления ключевыми узлами установки ЭП-300, предназначенной для производства пропилена. Особое внимание уделено узлу выделения пропан-пропиленовой фракции (ППФ), являющемуся критическим с точки зрения качества и выхода целевого продукта. Предложена иерархическая система управления, включающая реальную оптимизацию, предиктивное управление и адаптивные алгоритмы компенсации возмущений по составу сырья. На основе моделирования колонны разделения ППФ показано, что применение оптимальных стратегий управления позволяет увеличить выход пропилена на 4,2÷5,8% при снижении энергозатрат на ректификацию на 12÷15%.

Abstract. This article examines the issues of optimal control of process units for the EP-300 unit, designed for propylene production. Particular attention is paid to the propane-propylene fraction (PPF) separation unit, which is critical in terms of the quality and yield of the commodity product. A hierarchical control system is proposed, incorporating real-time optimization, predictive control, and adaptive algorithms to compensate for feedstock composition disturbances. Based on modeling of a PPF separation column it is shown that the application of optimal control strategies can increase propylene yield by 4.2–5.8% while reducing energy consumption for distillation by 12–15%.

Ключевые слова: Установка ЭП-300, пропилен, паровой крекинг, колонна разделения, оптимальное управление, предиктивное управление.

Keywords: EP-300 unit, propylene, steam cracking, separation column, optimal control, predictive control.

Large-capacity EP-300 units are industrial complexes designed for the combined production of ethylene and propylene, with a capacity of up to 300,000 tons per year. This production is achieved through the thermal pyrolysis of hydrocarbon feedstocks, including naphtha, straight-run gasoline, and liquefied gases [1]. The key process block of the EP-300 unit is the PPF extraction and separation system, as propylene and propane have similar physicochemical properties (relative volatility $\alpha \approx$ 1,1–1,3), making their separation an energy-intensive process requiring the use of distillation columns with a large number of theoretical plates (60–100) and a high reflux ratio (35). Insufficient control of this unit leads to losses of propylene with the propane fraction (up to 3–5%) and an increase in energy costs by 20–30% [2-9].

The purpose of this article is to develop a comprehensive system for optimal control of the propylene production process at a large-capacity EP-300 plant with a focus on the PPF separation installation to maximize the yield of the commodity product while minimizing specific energy consumption. The propylene production process in the EP-300 unit includes the following main stages:

1) feedstock pyrolysis is the thermal decomposition of hydrocarbons at a temperature of 780–850°C and a pressure of 0,2–0,3 MPa in the presence of water vapor (steam/feedstock = 0,3–0,5 wt.) in convection-radiation furnaces;

2) quenching and compression is the rapid cooling of pyrolysis gas to 35–40 °C, followed by four-stage compression to 3,5–4,0 MPa;

3) the PPF separation block is sequential rectification in demethanization, deethanization, and depropanization columns to produce a propane-propylene fraction with a propylene concentration of 65–85%;

4) separation of PPF is a high-precision rectification in the K-17 column to obtain commercial propylene (purity ≥ 99,6%) and recycled propane.

For the optimal control problem, a non-stationary model of the K-17 distillation column was developed, based on the equations of material and heat balance:

$$\begin{cases} \frac{dM_i}{dt} = L_{i-1} + V_{i+1} - L_i - V_i + F\delta_{i,f} - D\delta_{i,d} - W\delta_{i,\omega} \\ M_i \frac{dx_{i,j}}{dt} = L_{i-1}x_{i-1,j} + V_{i+1}y_{i+1,j} - L_i x_{i,j} - V_i y_{i,j} + F x_{f,j}\delta_{i,f} - D x_{d,j}\delta_{i,d} - W x_{\omega,j}\delta_{i,\omega} \\ \frac{dE_i}{dt} = L_{i-1}h_{i-1} + V_{i+1}H_{i+1} - L_i H_i - V_i H_i + Q_{reb}\delta_{i,reb} - Q_{cond}\delta_{i,cond} \end{cases} \quad (1)$$

where M_i is the mass of liquid on plate i; $x_{i,j}$, $y_{i,j}$ are the mole fractions of component j in the liquid and gas phases, respectively; L_i, V_i are the flows of liquid and gas, respectively; F, D, W are the feed, distillate and still residue flows, respectively; Q_{reb}, Q_{cond} are the heat loads of the boiler and dephlegmator, respectively.

The coke formation kinetics in pyrolysis furnaces are described by the empirical relationship:

$$\frac{dC_{coke}}{dt} = k_0 exp\left(-\frac{E_a}{RT}\right) \cdot C_{olefins}^n \quad (2)$$

where C_{coke} is the coke concentration on the surface of the pipes, $C_{olefins}^n$ is the concentration of olefins in the feedstock, $n \approx 1,2 \div 1,5$.

To construct a physically sound statement of the optimal control problem for the process of obtaining commodity ethylene, first formulate the control criterion. The target function is formulated as maximizing the annual profit from propylene production:

$$J = \max_{u(t)} \int_0^{T_{year}} [P_p \cdot F_p(t) \cdot \eta_p(t) - c_{energy}\, Q_{tot}(t) - c_{raw} \cdot F_{raw}(t)]dt - C_{reg}(t) \quad (3)$$

where P_p is the market price of propylene; $F_p$is the propylene flow into the PPF at the inlet of the separation column; $\eta_p$is the degree of propylene extraction into the commodity product; Q_{tot} is the total thermal load of the column; C_{reg} is the cost of catalyst regeneration in pyrolysis furnaces.

The constraints of the given problem are written as follows:

$$0{,}95 \le x_{P,dist} \le 1{,}0 \quad \text{(purity of commodity propylene)}$$
$$1{,}5 \le R \le 5{,}0 \quad \text{(phlegma number)}$$
$$1{,}6 \le P_{col} \le 2{,}0 \quad \text{(column pressure)}$$
$$\dot{m}_{coke} \le \dot{m}_{coke,max} \quad \text{(a limitation on the rate of coke formation)}$$
$$|u(t) - u(t-\Delta t)| \le \Delta u_{max} \quad \text{(a limitation on the rate of setting change)} \qquad (4)$$

To implement the process of optimal control for the studied process of obtaining propylene, a three-level control structure for the propylene production unit is proposed.

Level 1 (RTO). For the EP-300 unit, the following are optimized: pressure in the PPF separation column; phlegma number; reboiler temperature.

The algorithm accounts for catalyst degradation in furnaces and adjusts the pyrolysis temperature to maintain a stable PPF composition.

Level 2 (MPC). A predictive controller ensures:

- maintaining propylene purity in the distillate at 99,6±0,1% with feed composition fluctuations of ±5%;
- minimizing excess energy consumption by smoothing transient processes;
- coordinating the operation of the depropanization and PPF separation columns.

Level 3. Traditional PID controllers with adaptive tuning ensure stable operation:

- column pressure (by regulating the withdrawal of uncondensed gases);
- level in the dephlegmator (by regulating the phlegma flow);
- boiler temperature (by regulating the coolant flow).

The operation of the EP-300 PPF separation unit was simulated using Aspen HYSYS, followed by optimization in MATLAB/Simulink.

Steady-state optimization results:

- with a fixed phlegma number of R=4,0, the yield of propylene was 94,3%;
- with an optimized R=3,6 (taking into account the current relative volatility of α=1,22), the yield increased to 96,8% with a 13,5% reduction in the boiler heat load.

Results of dynamic modeling using MPC:

- with a step change in feed propylene concentration from 72% to 68%, the control system restored product purity to 99,6% in 28 minutes, compared to 52 minutes with a traditional PID system;
- the standard deviation of product purity decreased from 0,42% to 0,11%;
- excess energy consumption during transient conditions decreased by 22%.

Industrial testing on the EP-300 unit:

- increase in average commodity propylene yield from 93,1% to 97,4%;
- reduction in specific fuel gas consumption by 14,3%;
- increase in the pyrolysis furnace regeneration period by 8% due to temperature optimization based on predicted catalyst deactivation;
- reduction in the number of regeneration cycles by 17%.

The developed system for optimal control of the propylene production process on the EP-300 unit, integrating an economic optimizer, a predictive controller, and adaptive base control loops, demonstrates significant economic benefits:

1) an increase in commodity propylene yield by 4.2–5.8% due to optimization of the phlegma number and pressure in the PPF separation column, taking into account the current feed composition and market prices;

2) a reduction in energy costs for rectification by 12–15% while maintaining the required product purity (≥ 99.6%);

3) increased unit stability during feedstock quality fluctuations and gradual catalyst deactivation in the pyrolysis furnaces.

Note that promising areas for further research include:

- integrating a digital twin of the EP-300 unit for proactive optimization of operating modes before scheduled shutdowns;
- applying machine learning methods to predict the composition of the PPF based on real-time raw material analysis;
- developing decentralized control algorithms to coordinate the operation of the pyrolysis furnaces and the PPF separation block as a single system.

Список литературы:

1. Kuzmin S.T., Kozlov I.A. Opyt vnedreniya i ehkspluatacii avtomatizirovannykh sistem upravleniya krupnotonnazhnym proizvodstvom ehtilena, Moskva, CNIITEhneftekhim, 1984.

4. Melikov, E.A., Magerramova, T.M., Safarova, A.A. Logical-Linguistic Model for Reactor Cleaning from Impurities. 15th International Conference on Applications of Fuzzy Systems, Soft Computing and Artificial Intelligence Tools. Lecture Notes in Networks and Systems, vol 610. Springer, Cham., 2023, pp. 321-329. https://doi.org/10.1007/978-3-031-25252-5_44

5. Safarova A.A., Melikov E.A., Magerramova T.M. Principles of modeling and optimal control of a fraction purification reactor from micro impurities, III International scientific and practical conference "Technologies, materials science and engineering" (EEA-III-2024), AIP Conference Proceedings, AIP Publishing, vol. 3243, Issue 1, 2024, 020014. https://doi.org/10.1063/5.0247869

6. Guseinov I.A., Kurbanov Z.G., Melikov E.A., Efendiev A.I., Efendiev I.R. Nonstationary Multistage Process Control in the Petrochemical Industry. Journal of Computer and Systems Sciences International, Pleiades Publishing, Ltd., 2014, Vol. 53, No. 4, pp. 556-564. https://doi.org/10.1134/S1064230714030095

7. Safarova A.A., Melikov E.A, Magerramova T.M. Design of a cascade controller based on a predictive model. Fourth International Conference on Digital Technologies, Optics, and Materials Science (DTIEE 2025), Proceedings of SPIE, Vol. 13662, 136620H, 2025. https://doi.org/10.1117/12.3072311

8. Safarova A.A., Melikov E.A, Magerramova T.M., Xanbutaeva N.A. Control algorithmization of complex technological systems under uncertainty conditions. Fourth International Conference on Digital Technologies, Optics, and Materials Science, Proceedings of SPIE, Vol. 13662, 2025, 1366204. https://doi.org/10.1117/12.3071739

9. Melikov E.A. Modeling, algorithmization, and solution of the optimal control problem for the ethylene production complex under conditions of incomplete information. Nafta-Gaz, 2025, No. 5, pp. 359-369. https://doi.org/10.18668/NG.2025.05.07.