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РАЗРАБОТКА МАТЕМАТИЧЕСКОЙ МОДЕЛИ И РЕШЕНИЕ ЗАДАЧИ ОПТИМИЗАЦИИ НА УСТАНОВКЕ ПОЛУЧЕНИЯ БИТУМА
DEVELOPMENT OF A MATHEMATICAL MODEL AND SOLUTION OF AN OPTIMIZATION PROBLEM AT A BITUMEN PRODUCTION INSTALLATION

Аннотация. Производство битума является одним из важных направлений нефтепереработки, используемым в дорожном строительстве, гидроизоляции и различных отраслях промышленности. Качество битума и эффективность процесса во многом зависят от режима работы технологических установок. Поэтому моделирование и оптимизация процесса извлечения битума имеют большое научное и практическое значение в современной нефтехимии. В статье разработана модель процесса работы реактора, используемого на установке по получению битума. Модель учитывала физико-химические процессы, тепло- и массоперенос, а также кинетику реакций, происходящих в реакторе. На основе разработанной модели сформулирована задача оптимизации для определения оптимальных параметров управления процессом. В ходе оптимизации в качестве целевой функции выбрано улучшение качественных показателей битума, снижение энергопотребления и повышение производительности процесса. В результате применения различных методов математической оптимизации определены более эффективные режимы процесса.

Abstract. Bitumen production is one of the important directions of the oil refining, used in road construction, waterproofing and various industrial sectors. The quality of bitumen and the efficiency of the process largely depend on the operating mode of technological facilities. Therefore, modeling and optimization of the bitumen recovery process is of great scientific and practical importance in modern petrochemistry. In the article, a mathematical model of the reactor operating process used in the bitumen recovery plant was developed. The model took into account the physical and chemical processes, heat and mass transfer, as well as reaction kinetics occurring in the reactor. Based on the developed model, an optimization problem was formulated to determine the optimal control parameters of the process. During optimization, the objective function was taken to be improving the quality indicators of bitumen, reducing energy consumption and increasing the productivity of the process. As an application result of various mathematical optimization methods, more efficient process modes were determined.

Ключевые слова: Производство битума, математическая модель, процесс окисления, кинетика реакции, нефтеперерабатывающая промышленность.

Keywords: Bitumen production, mathematical model, oxidation process, reaction kinetics, oil refining industry.

The petroleum products role in the development of modern industry and infrastructure is extremely significant. Among these products, bitumen occupies a special place, widely used in road construction, waterproofing materials, and other construction applications. The development of road infrastructure, the expansion of the construction sector, and the growth in industrial production have led to a sustained increase in demand for bitumen. Bitumen is obtained primarily during oil refining by oxidizing heavy petroleum residues or by other technological methods. These processes are carried out in specialized technological apparatuses – reactors. The chemical and physical processes occurring in the reactor, including oxidation reactions, heat and mass transfer, mixing, and phase interactions, have a direct impact on the bitumen quality. Therefore, the correct selection of the reactor operating mode and optimal control of the process parameters are of great importance for increasing the bitumen production efficiency [1].

Mathematical modeling is considered a key tool in studying and controlling technological processes in the modern oil refining industry. This approach facilitates a more in-depth understanding of process installation operation, the determination of optimal operating modes, and effective process control [2-6]. Mathematical modeling of reactors used in bitumen production facilities allows for the analysis of the interactions between key process parameters - temperature, pressure, air and feedstock flows, oxidation time, and other process parameters. Correctly selecting these parameters plays a crucial role in determining the physical and chemical bitumen properties, including such parameters as penetration, softening point, and viscosity. The use of mathematical optimization methods enables more efficient process control, reduced production costs, and enhanced competitiveness of industrial enterprises. The complexity of the bitumen production process and its dependence on numerous process parameters make mathematical modeling and optimization particularly relevant. Developing a mathematical model of the reactor allows for a more accurate description of technological processes, improvement of control systems, and determination of optimal process conditions.

In this article utilized methods such as mathematical modeling, systems analysis, optimization techniques, and computer simulation. These methods allow for a comprehensive study of the heat, mass transfer, and oxidation reactions occurring in the reactor [7]. The bitumen production process was analyzed using a systems approach, identifying the key stages: feedstock feed to the reactor, oxidation, air supply, heat transfer, and finished product yield. The reactor involves processes such as heavy oil residues oxidation, mass transfer between phases, heat generation due to exothermic reactions, and hydrodynamic mixing. The systems analysis allowed us to determine the interactions between these processes and select the key process parameters for constructing a mathematical model. Figure 1 shows the technological scheme for obtaining bitumen by the oxidation process.

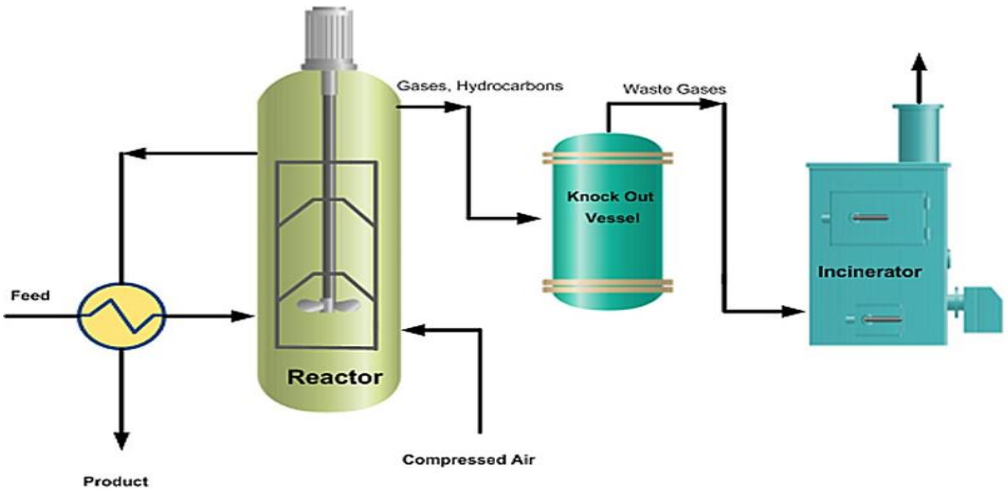

Figure 1. Technological scheme for obtaining bitumen by the oxidation process

The process technological scheme used in the bitumen production process operates on the principle of heavy oil residues oxidation with air. The process begins with the introduction of raw materials into the system and their preliminary heating in a heat exchanger. The heated raw materials enter the reactor, where they are mixed with compressed air and undergo oxidation reactions. Within the reactor, mass transfer between the air and liquid phases, heat release due to exothermic reactions, and hydrodynamic mixing processes occur. These processes change the physicochemical properties of the raw materials, and bitumen is formed. After the oxidation process is complete, the finished bitumen product is removed from the reactor bottom. The gases formed during the process are separated from the reactor top and first sent to a gas separation apparatus, where the liquid fractions are separated, and the exhaust gases are then disposed of in a special incinerator. Thus, this process technological scheme sequentially ensures the main bitumen production stages: raw material preparation, oxidation reaction, product separation, and safe gas disposal [8].

To apply the model practically, the processes occurring in a bitumen production installation were studied using computer simulation. This approach allows for experiments in a simulated environment that would be difficult or expensive to conduct at real industrial facilities, as well as for analyzing various process operating modes. The modeling process took into account the key process parameters affecting reactor operation. Of particular importance among these parameters are temperature, air flow rate, feedstock feed rate, and oxidation time. The analysis allowed us to determine temperature changes over time, the kinetics of oxidation reactions, the mechanism by which air flow influences the process, and the energy balance occurring in the reactor. To ensure the reliability of the results obtained through computer modeling, a separate assessment of the model's adequacy was conducted. For this purpose, the modeling results were compared with actual process data obtained at pilot and industrial facilities. The comparison showed that the model corresponded reasonably well to the actual process and confirmed its suitability as a reliable tool for studying and optimizing the bitumen production process. The use of models and modeling methods enables more effective control of the bitumen production process and improves the efficiency of the industrial facilities. To improve the process efficiency and determine the optimal operating reactor mode, optimization methods were used in the study. The optimization problem was based on the principle of maximizing the objective function and was aimed at determining the optimal values of the main controlled process parameters. For this purpose, key process variables such as reactor temperature, air flow rate, oxidation time, and feedstock consumption were taken into account. During the optimization, the main objectives were to improve bitumen quality indicators, reduce energy consumption, and increase process productivity. Statistical and comparative analysis methods were used to evaluate the obtained results reliability, and the optimal process parameters were determined by comparing the results obtained in various operating modes. By optimizing key variables such as reactor temperature, air flow rate, oxidation time, and feedstock consumption, more efficient control of the bitumen production process is achieved. This approach creates the conditions for both a technologically stable and reliable operating mode and the production of a high-quality product with minimal energy consumption. Therefore, optimizing these parameters is considered a key research area in the development and optimization of models for bitumen production installation.

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