MODELING THE STEAM GENERATION PROCESS IN EVAPORATION UNITS OF THE OIL AND GAS INDUSTRY

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Abstract. *Evaporation units are an important component of technological processes in industrial enterprises. They are widely used for concentrating solutions, removing excess moisture, and improving product quality. In particular, evaporation apparatuses play a crucial role as heat exchange equipment in the chemical, food, and oil and gas industries. Therefore, in-depth study of the evaporation process, development of its mathematical model, and optimal control of process parameters are considered important scientific and practical tasks. In this research, the issue of mathematical modeling of the steam preparation process in industrial evaporation units is examined. A system of differential equations based on material and heat balance equations was developed to describe the process. The obtained mathematical model makes it possible to analyze the dynamic characteristics of the technological object and determine the time variation of process parameters. The modeling process was implemented using the Simulink visual modeling environment. Based on the results, the patterns of changes in product concentration and enthalpy over time during the evaporation process were determined. The results of the study are important for effective control of industrial evaporation units, improving energy efficiency, and optimizing technological processes.*

Keywords: *evaporation process, mathematical modeling, material balance, heat balance, Simulink, concentration, enthalpy, dynamic model.*

1. Introduction

In industrial enterprises, the evaporation process plays an important role in concentrating solutions, removing excess water from liquids, and processing various technological products. According to the Decree of the President of the Republic of Uzbekistan dated September 11, 2023, No. PF-158 "On the Strategy 'Uzbekistan – 2030,'" several important tasks have been defined to ensure the continuous supply of necessary energy resources to economic sectors and the population [1]. In particular, these tasks include increasing the amount of electricity supplied to economic sectors and the population to 120 billion kWh, increasing natural gas production to 62 billion cubic meters, doubling the energy efficiency of economic sectors, and modernizing the infrastructure for the distribution, generation, and delivery of electricity and natural gas to consumers. \

The implementation of these tasks is partly dependent on the efficiency of evaporation processes in the energy sector, which is influenced by the design characteristics of the equipment, heat transfer conditions, and the optimal control of technological parameters. Evaporation units are widely used in the chemical and oil and gas industries, where they enable modification of product composition and achievement of the required concentration. In order to effectively organize and control the evaporation process, it is essential to develop a mathematical model of this technological system [2,3]. Mathematical modeling makes it possible to conduct an in-depth theoretical analysis of the process, determine its static and dynamic characteristics, and develop optimal control algorithms. Furthermore, in evaporation units operating under vacuum conditions,

the boiling temperature of the solution can be reduced, which helps preserve heat-sensitive substances and improve product quality.

2. Literature Review

Issues related to the modeling of evaporation processes and the improvement of energy efficiency have been studied in numerous scientific works [4–7]. In a study devoted to the mathematical modeling of multiple-effect evaporation units and the evaluation of their energy efficiency, the main technological parameters of the evaporation process were identified and the possibilities of reducing energy consumption were analyzed (Kaya et al., 2007).A mathematical model of a multiple-effect evaporation unit used at an industrial scale was developed, and the influence of technological parameters on process efficiency and product quality in the production of tomato concentrate was investigated (Miranda et al., 2005).

A mathematical model based on lumped parameters was developed to describe the heat transfer processes occurring in the evaporator section of a heat pump, and the operating characteristics of the device were analyzed (Nyers et al., 2014). In addition, a mathematical model of a counter-current multiple-effect evaporation system used for fruit juice concentration was developed, and the influence of technological parameters on process performance and energy efficiency was analyzed (Ruan et al., 2015).

3. Research Methodology

In this study, the mathematical modeling method was used to investigate the steam generation process in industrial evaporation units. To describe the process, a mathematical model based on material and heat balance equations was developed. A system of differential equations was formulated to represent the static and dynamic states of the evaporation process. The main parameters analyzed included the mass of the product, its concentration, and the change in enthalpy over time.

Based on the developed mathematical model, computer simulation of the process was carried out using the Simulink visual modeling environment. In the software environment, a functional block diagram of the process was constructed. Using the developed model, the dynamic characteristics of the evaporation process and the patterns of change in the main parameters were studied.

4–5. Analysis and Results

In the mathematical modeling of the evaporation process, analytical approaches are applied, taking into account the physicochemical phenomena occurring during the process, the properties of the processed mixture, as well as the structural parameters of the equipment. This approach requires a thorough theoretical analysis of the process and the development of equations describing the operation of the equipment under static and dynamic operating conditions.

In the oil and gas industry, evaporation units are widely used as heat transfer equipment. In devices operating under vacuum conditions, the secondary vapor generated during the evaporation process is condensed through a special condenser, while the remaining gases are removed using a pump [8]. This method significantly reduces the boiling temperature of the solution, which prevents the degradation of heat-sensitive substances and preserves product quality.

Furthermore, the use of a vacuum system provides several advantages:

- increases the energy efficiency of the evaporation process;
- enhances the temperature difference, which improves heat transfer efficiency;

- helps optimize the heat transfer surfaces of the equipment and reduce metal consumption.

In mathematical modeling of the evaporation process, the fundamental equations are the material and heat balance equations. The material balance equation in the static state expresses the mass equilibrium in the evaporation apparatus and mathematically determines the relationship between the inlet and outlet flows in the process.

$$S_0 = S_k + W \quad (1)$$

where S_0 – the feed extract supplied to the evaporator, kg/h; W – the rate of evaporated water, kg/h; S_k – the flow rate of the concentrated extract, kg/h.

To derive the dynamic material balance equation, a variable m (kg) was introduced to represent the mass of the extract in the evaporator and the possible material losses within the apparatus. In this case, the material balance can be expressed in the form of a dynamic equation.

$$\frac{dm}{dt} = S_0 - S_k - W \qquad (2)$$

In the technological process, since the change in the concentration of the evaporating product is described by a dynamic equation, a variable b was introduced to represent the time-dependent concentration. The dynamic behavior of the concentration change is expressed in the following equation.

$$\frac{db}{dt} = \frac{S_0 \cdot (b_0 - b) - W \cdot b}{m} \qquad (3)$$

In the evaporation process, in order to describe the dynamic behavior of the heat balance, it is necessary to know the heat supplied to the unit, the heat losses, and the enthalpy of the process under stationary operating conditions.

$$\frac{dh}{dt} = \frac{S_0 \cdot (h_0 - h) - W \cdot (i - h) + Q - L}{b} \qquad (4)$$

where h_0 – the initial enthalpy of the evaporating product, J/kg; i – the enthalpy of the secondary vapor, J/kg; Q – the heat supplied to the evaporator body, J/h; Q – the heat loss in the evaporator body, J/h.

The obtained system of differential equations makes it possible to model the dynamics of the evaporation process in a single body of the evaporation unit [9–12]. The modeling scheme of this technological process was developed using the Simulink visual modeling software package (shown in Figure 9). For the constructed scheme to function correctly, all blocks must be properly connected, and the corresponding parameters and coefficients must be specified.

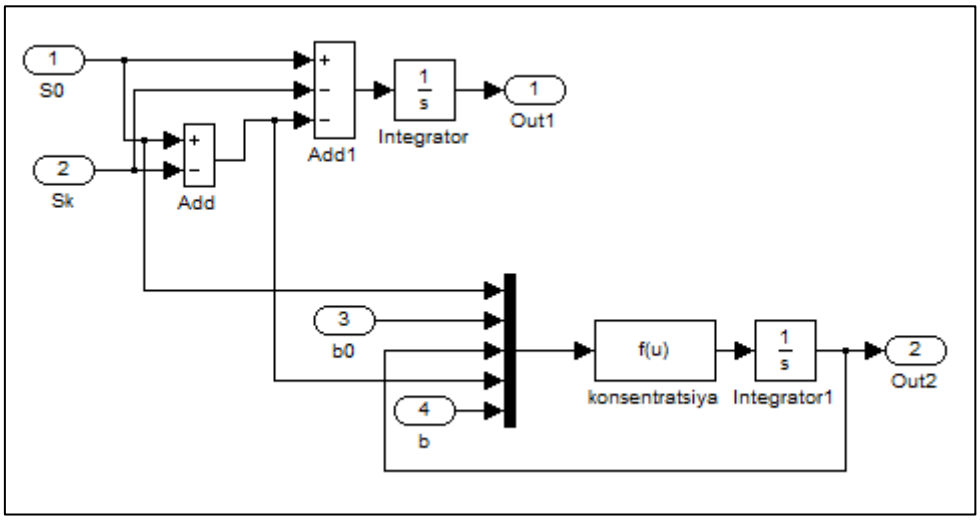


Figure 1. Model of the process in the Simulink package.

The presented modeling scheme is used to simulate the process when the initial data are provided.

The following graphs show the changes in concentration and enthalpy values (Figure 2).

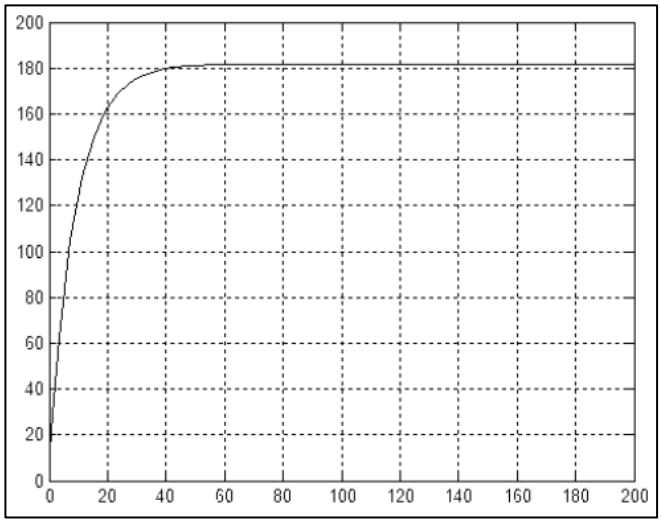


Figure 2. Change in the concentration value of the evaporating product.

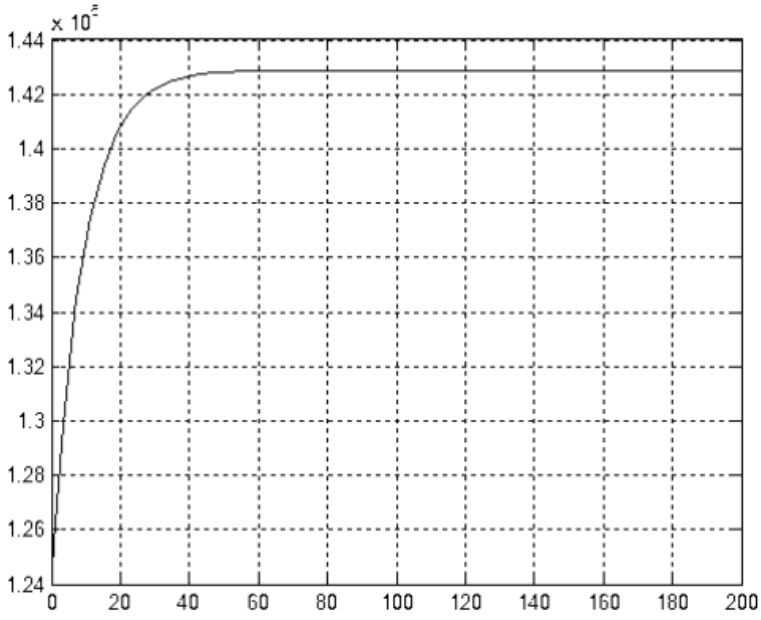


Figure 3. Change in the enthalpy value of the evaporating product.

To effectively automate the evaporation process and develop an optimal control system, it is necessary to model the technological object using an analytical approach. This process is based on a thorough analysis of the technological system, identification of controllable parameters, and the formation of control algorithms based on mathematical models.

6. Conclusion and Recommendations

In this research, the issue of mathematical modeling of the steam generation process in industrial evaporation units was investigated. During the study, a mathematical model based on material and heat balance equations was developed to describe the evaporation process. A system of differential equations representing the static and dynamic states of the process was formulated, and the time-dependent changes of technological parameters were analyzed.

Using the Simulink visual modeling environment, a functional model of the process was constructed, and the dynamics of changes in the concentration and enthalpy of the evaporating product were obtained in graphical form. The obtained results make it possible to analyze the technological characteristics of the evaporation process more deeply and ensure more efficient control of the process.

Based on the research results, the following recommendations are proposed:

- to widely use mathematical modeling methods to optimize the operating modes of industrial evaporation units;
- to reduce energy consumption by controlling the evaporation process through automated control systems;
- to improve vacuum evaporation systems in order to increase the efficiency of heat transfer processes;
- to apply the developed mathematical model in the design and modernization of technological processes.

The results of this study are important for improving the efficiency of industrial evaporation units, ensuring rational use of energy resources, and enhancing technological processes.

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