MODELING OF THE NATURAL GAS FRACTIONATION PROCESS

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Annotatsiya. Tabiiy gaz – elektr energiyasi ishlab chiqarish, kimyo sanoati va maishiy sohalarda keng qo‘llaniladigan muhim energiya manbaidir. Biroq, konlardan olingan tabiiy gaz murakkab ko‘p komponentli aralashma bo‘lib, uni tegishli ajratishsiz to‘g‘ridan-to‘g‘ri ishlatib bo‘lmaydi. Fraktsiyalash – gazni qayta ishlash zavodlarida muhim bosqich bo‘lib,uglevodorodlarniqimmatli tijoriy fraktsiyalarga ajratishga imkon beradi. Ushbu maqolada tabiiy gazni fraktsiyalash jarayoni uchun matematik modellashtirish yondashuvi taqdim etilgan. Model material va energiya balans tenglamalari bilan bug‘–suyuqlik muvozanati munosabatlarini birlashtirish asosida ishlab chiqilgan. Fraktsiyalash ustuni barqaror holat sharoitida ishlaydigan ko‘p bosqichli tizim sifatida tasvirlangan. Ajratish samaradorligiga sezilarli ta’sir ko‘rsatadigan bosim, harorat, refluks nisbati va kirish aralashmasi kabi ish parametrlari alohida e’tibor bilan ko‘rib chiqilgan. Modellashtirish yondashuvi O‘zbekiston sharoitida ishlayotgan gazni qayta ishlash zavodlariga xos sharoitlarni aks ettiradi. Simulyatsiya natijalari taklif qilingan modelning ajratish samaradorligini tahlil qilish va optimal ish rejimlarini aniqlash uchun qo‘llanilishi mumkinligini ko‘rsatadi. Ishlab chiqilgan model jarayonni optimallashtirish, energiya samaradorligini oshirish va tabiiy gaz fraktsiyalash birliklarini modernizatsiya qilishda foydalanilishi mumkin.

Kalit so‘zlar: tabiiy gazni qayta ishlash, fraktsiyalash, matematik modellashtirish, bug‘–suyuqlik muvozanati, jarayonni simulyatsiya qilish

Аннотация. Природный газ является ключевым энергетическим ресурсом, широко используемым в электроэнергетике, химической промышленности и бытовом секторе. Однако природный газ, добываемый из месторождений, представляет собой сложную многокомпонентную смесь, которая не может использоваться напрямую без соответствующего разделения. Фракционирование является критическим этапом на газоперерабатывающих заводах, обеспечивая разделение углеводородов на ценные коммерческие фракции. В данной работе представлен подход математического моделирования процесса фракционирования природного газа. Модель разработана на основе уравнений материального и энергетического баланса

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в сочетании с соотношениями пар–жидкость равновесия. Фракционная колонна описывается как многоступенчатая система, работающая в условиях стационарного режима. Особое внимание уделено параметрам эксплуатации, таким как давление, температура, коэффициент возврата конденсата (рефлюкс) и состав подачи, которые существенно влияют на эффективность разделения. Подход моделирования отражает условия, типичные для газоперерабатывающих заводов, включая объекты, работающие в Узбекистане. Результаты моделирования демонстрируют применимость предложенной модели для анализа производительности разделения и определения оптимальных режимов работы. Разработанная модель может использоваться для оптимизации процессов, повышения энергетической эффективности и модернизации установок фракционирования природного газа.

Ключевые слова: переработка природного газа, фракционирование, математическое моделирование, равновесие пар–жидкость, моделирование процесса

Abstract. Natural gas is a key energy resource widely used in power generation, chemical industries, and domestic sectors. However, natural gas obtained from reservoirs represents a complex multicomponent mixture that cannot be utilized directly without appropriate separation. Fractionation is a critical stage in gas processing plants, enabling the separation of hydrocarbons into valuable commercial fractions. This paper presents a mathematical modeling approach for the natural gas fractionation process. The model is developed on the basis of material and energy balance equations combined with vapor–liquid equilibrium relationships. The fractionation column is described as a multistage system operating under steady-state conditions. Particular attention is given to operating parameters such as pressure, temperature, reflux ratio, and feed composition, which significantly influence separation efficiency. The modeling approach reflects conditions typical for gas processing plants, including those operating in Uzbekistan. Simulation results demonstrate the applicability of the proposed model for analyzing separation performance and identifying optimal operating regimes. The developed model may be used for process optimization, energy efficiency improvement, and modernization of natural gas fractionation units.

Keywords: natural gas processing, fractionation, mathematical modeling, vapor–liquid equilibrium, process simulation

INTRODUCTION.

Natural gas occupies a central position in the modern energy balance due to its high calorific value and relatively low environmental impact. Many countries

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rely on natural gas as a primary fuel for electricity generation and as a feedstock for chemical and petrochemical industries. At the same time, natural gas extracted from underground formations contains various hydrocarbon components and impurities that must be separated before utilization [1,2].

The composition of raw natural gas typically includes methane as the main component, along with ethane, propane, butanes, and heavier hydrocarbons [2]. These components differ significantly in their physical and thermodynamic properties. In order to meet industrial and commercial standards, natural gas must undergo a sequence of processing stages, among which fractionation plays a decisive role [1].

Fractionation is based on the separation of hydrocarbon components according to differences in boiling points. This process is commonly implemented in distillation columns operating at controlled pressure and temperature levels. The efficiency of fractionation units directly affects product recovery, energy consumption, and overall economic performance of gas processing plants [1,3].

In gas-producing countries such as Uzbekistan, where natural gas constitutes a major share of the energy sector, improving the performance of fractionation units is of strategic importance. Due to the complexity of multicomponent systems, experimental optimization of fractionation processes is often impractical [6]. Therefore, mathematical modeling has become an essential tool for analyzing and improving gas separation technologies [10].

The objective of this study is to develop a mathematical model of the natural gas fractionation process that can be used for performance analysis and optimization under typical industrial operating conditions [6,7].

Overview of Previous Research. Theoretical and practical aspects of natural gas fractionation have been widely discussed in international scientific literature. Classical studies focus on distillation theory and equilibrium-stage modeling of multicomponent systems. These approaches provide a foundation for understanding separation mechanisms in fractionation columns.

With the advancement of computational tools, researchers have increasingly applied rigorous thermodynamic models to simulate natural gas separation processes. Modern studies emphasize the use of equations of state and process simulators to predict vapor–liquid equilibrium behavior and energy requirements.

In recent years, researchers in Uzbekistan have also contributed to the study of gas processing technologies. Their work primarily addresses issues related to energy efficiency, adaptation of existing equipment, and modeling of technological processes under local operating conditions. These studies highlight the importance of mathematical modeling as a tool for improving gas processing performance.

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Despite existing research, there remains a need for generalized modeling approaches that combine classical separation theory with practical considerations relevant to gas processing plants. This study seeks to contribute to this area by developing a transparent and adaptable mathematical model.

Description of the Natural Gas Fractionation Process. The natural gas fractionation process is typically preceded by pretreatment stages such as dehydration and removal of acidic components. Once impurities are removed, the hydrocarbon-rich stream is directed to the fractionation section.

Fractionation is carried out in distillation columns designed to separate hydrocarbon components into specific fractions. The feed enters the column at a selected stage, where it contacts ascending vapor and descending liquid streams. Heat input is provided by a reboiler located at the bottom of the column, while a condenser at the top removes heat and generates reflux.

The separation efficiency depends on several factors, including feed composition, column pressure, temperature profile, and reflux ratio. Variations in these parameters can significantly affect product purity and recovery, making reliable modeling essential for process analysis.

Table 1.

Modeling Assumptions. To formulate a practical mathematical model, the following assumptions are introduced:

Steady-state operation of the fractionation column
Thermodynamic equilibrium between vapor and liquid phases on each stage
Negligible pressure drop along the column height
Absence of heat losses to the surroundings
Uniform mixing on each theoretical stage

These assumptions are consistent with approaches commonly used in gas processing studies.

Mathematical Model Formulation

Material Balance Equations. For each component i on stage j of the column, the material balance can be expressed as:

$$L_{j+1}x_{i,j+1} + V_{j-1}y_{i,j-1} + F_j z_{i,j} = L_j x_{i,j} + V_j y_{i,j}$$

where liquid and vapor flow rates are represented by L and V, respectively.

Energy Balance Equations. The energy balance for stage j is written as:

$$L_{j+1}h_{L,j+1} + V_{j-1}h_{V,j-1} + Q_j = L_j h_{L,j} + V_j h_{V,j}$$

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Here, h_L and h_V denote the specific enthalpies of liquid and vapor phases.

Phase Equilibrium Relations. Vapor–liquid equilibrium is described using equilibrium coefficients:

$$y_{i,j} = K_{i,j} x_{i,j}$$

The equilibrium coefficients depend on temperature, pressure, and component properties and are determined using appropriate thermodynamic models.

Results and Discussion. Simulation of the mathematical model reveals that separation efficiency increases with higher reflux ratios, although this improvement is accompanied by increased energy consumption. Column pressure strongly influences vapor–liquid equilibrium and determines achievable product purity.

The model also shows sensitivity to feed composition, which is particularly important for gas processing plants where reservoir characteristics vary over time. These results are consistent with observations reported in studies conducted at gas processing facilities, including those operating in Uzbekistan.

The developed model provides valuable insights into the relationship between operating parameters and separation performance, making it suitable for optimization studies.

Conclusion. A mathematical model of the natural gas fractionation process has been developed based on mass and energy balance equations combined with vapor–liquid equilibrium relations. The model adequately represents the behavior of multicomponent hydrocarbon separation under steady-state conditions.

The results demonstrate that operating parameters such as reflux ratio, pressure, and feed composition play a crucial role in determining separation efficiency. The proposed modeling approach can be applied for analyzing, optimizing, and modernizing fractionation units in natural gas processing plants.

Future research may focus on extending the model to dynamic conditions and integrating advanced control strategies.

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