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CALCULATION OF SINGLE VAPORIZATION DURING SEPARATION OF GAS CONDENSATE

Abstract. This article examines the advantages of stabilizing crude oil and gas condensate to extract the most volatile hydrocarbons (C₁–C₄). Stabilization reduces light fraction losses due to evaporation by up to 80% and prevents corrosion of equipment and pipelines along the route from the Karachaganak oil and gas condensate field to refineries.

A comparative analysis of effective stabilization methods is presented, including three-stage separation, distillation in a stabilization column, and their combination.

Phase equilibrium constants and distillate fractions were calculated using the bisection method implemented in the Pascal programming environment. Based on the calculations, optimal parameters for the three-stage separation process were determined: first stage — 1 MPa, 35 °C; second stage — 0.3 MPa, 35 °C; third stage — 0.1 MPa, 35 °C. These parameters reduce the vapor pressure of stabilized condensate to 66.7 MPa. The three-stage scheme offers advantages such as simplicity and relatively low capital and operational costs. To enhance stabilization efficiency, it is proposed to combine vapor streams from the second and third stages and direct them to a distillation column with 11 sieve trays. The optimized column operation (3.6 MPa, top temperature 26.5 °C, bottom temperature 81 °C) ensures effective separation into methane, ethane, and heavier hydrocarbons (C₃+), which are returned to the stabilized condensate stream. The methane-ethane fraction is considered a promising feedstock

for the petrochemical industry.

Key words. Gas condensate stabilization, single evaporation, light carbon compounds., three-stage separation, petrochemical feedstock.

Introduction. Gas condensate stabilization is a thermodynamic process aimed at removing light volatile components with low boiling points—primarily methane, ethane, propane, and butane—from an unstable hydrocarbon mixture. The purpose of the process is to bring the gas condensate to a stable state, characterized by minimal evaporation and the absence of vapor phase formation under ambient temperature and atmospheric pressure conditions [1-3].

The stabilization process is based on the principles of phase equilibrium, whereby changes in temperature and pressure lead to the evaporation of light fractions. In practice, stabilization is carried out through stepwise pressure reduction, preheating of the feedstock, and/or the use of distillation columns. As a result, the raw material is separated into a stable liquid phase enriched with C5+ hydrocarbons and a gas phase consisting of methane, ethane, propane, and butane. The resulting stabilized gas condensate has increased density, reduced volatility, and can be used as a component of motor fuel, as feedstock for petrochemical synthesis, or as an export product [4,5].

Various types of technological equipment are used for stabilization, including heat exchangers, separators, heaters, distillation columns, condensers, and compressor units for the utilization of separated light hydrocarbons. The choice of stabilization scheme—single-stage or multi-stage—depends on the composition of the raw material, the required quality of the final product, and the technical conditions of the facility. Multi-stage stabilization ensures more precise control over the composition of the final product and efficient utilization of all condensate components [6,7].

Failure to stabilize gas condensate can lead to a number of serious technical, environmental, and economic consequences. Unstable gas condensate contains a significant amount of light volatile hydrocarbons (C₁–C₄), which exist in the gas phase under normal conditions. During storage and transportation, intensive evaporation of light components occurs, leading to increased pressure in tanks, leaks through valve and pipeline seals, and the potential for emergency situations including leaks, fires, and explosions—especially in high-temperature conditions. The economic losses of an enterprise that neglects stabilization during the preparation stage can exceed \$17–21 million per year [8,9].

From an environmental perspective, the evaporation of unstable fractions contributes to the release of hydrocarbon vapors into the atmosphere, negatively impacting the environment and potentially violating air quality regulations. Additionally, such emissions increase the risk of forming explosive mixtures in industrial working areas [10].

Transporting unstable gas condensate requires strict conditions, including the use of specialized sealed tanks and cooling systems, which increases logistics costs. Hydrocarbon losses due to evaporation reduce the commercial value of the product. At processing plants, unstable condensate can disrupt technological processes, increase the load on gas recovery systems, and reduce overall processing efficiency [11].

Therefore, gas condensate stabilization is an essential part of industrial hydrocarbon feedstock preparation. It ensures product compliance with safety standards, enhances market value, and promotes more efficient use of hydrocarbon resources through the extraction of valuable components for further processing or commercial application.

Research Methods

The separation of gas condensate is a complex multicomponent process that combines physical phenomena and mass transfer between the gas and liquid phases. To develop mathematical models capable of providing accurate predictions, it is essential to consider the physicochemical principles governing these processes. At the same time, the model must maintain acceptable computational complexity and be solvable using well-established numerical methods [12]. To meet these requirements, it is assumed that equilibrium conditions are achieved during the separation process and that the mixture components undergo single-stage flash evaporation.

Based on these assumptions, the separation model includes the calculation of phase equilibrium constants and determination of the distillate fraction using material balance equations for both gas and liquid phases.

The composition of the feedstock has a decisive influence on the optimal parameters for gas condensate separation. The main objective of the process is the efficient separation of the multiphase gas condensate mixture into gas and liquid fractions (condensate and water). The pressure, temperature, and configuration of the process scheme depend on the physicochemical characteristics of the incoming feedstock.

With a high content of heavy hydrocarbons (C_5+ fractions), it is necessary to maintain elevated pressures and reduced temperatures in the separators to maximize condensate recovery, since these fractions condense only under specific phase equilibrium conditions. In the case of a predominance of light fractions (C_1 – C_4), one or two separation stages under moderate conditions may be sufficient.

As input data for the calculations, the composition of crude oil and gas condensate from the Karachaganak gas condensate field was used. Calculations were performed to determine the distillate fraction and the molar share of the liquid and gas phases during single-stage evaporation. The temperature varied in the range of 0 to 35 °C in 5 °C increments. The total pressure was set at 1 MPa in the first separator, 0.3 MPa in the second, and 0.1 MPa in the final separator. The conceptual process flow involves three-stage separation, where the degassing pressure at each subsequent stage is lower than the previous one (Figure 1). The raw feed enters the first separator, where the vapor phase is removed and sent to the gas treatment unit, while the liquid phase proceeds to the second separator. A similar process occurs in the third separator to produce stabilized gas condensate.

To ensure the solvability of the model while maintaining acceptable calculation accuracy, the following assumptions were made: equilibrium is reached between phases at each stage of separation, and the mixture components undergo single-stage flash evaporation. The process is considered isothermal at each separation stage and is modeled as a sequence of three stages with decreasing pressure: 1 MPa → 0.3 MPa → 0.1 MPa [13,14]. A comparison of the proposed model with other methods demonstrated its effectiveness for basic calculations and the preliminary stages of process design. For more precise modeling of complex multicomponent systems, more advanced approaches—such as hybrid models or models based on PVT analysis—are recommended.

Future research will include comparative testing to determine the applicability of various models and to optimize gas condensate separation processes.

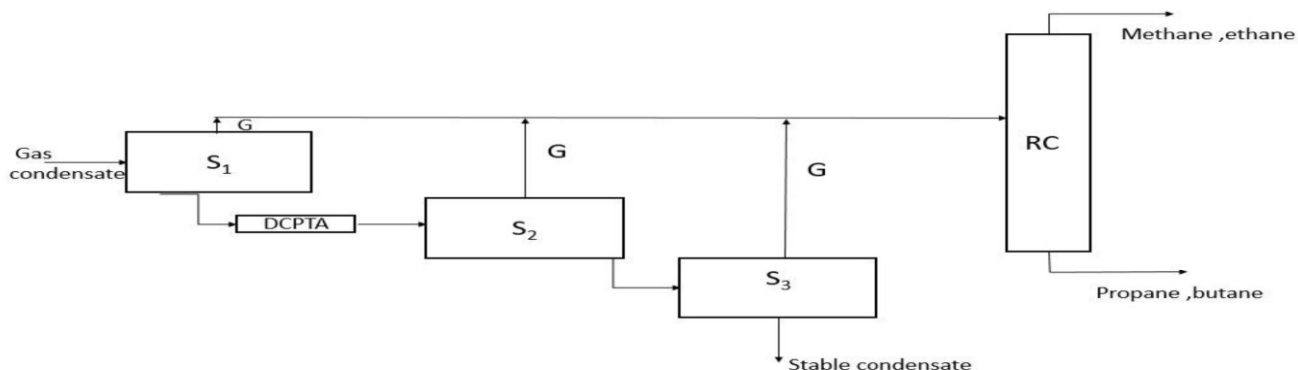


Figure 1 – Process flow diagram of the gas condensate separation unit:

S – Separators; G – Gases; RC – Rectification column; DCPTA – Diffuser-convergent pipe-type apparatus.

The main equation for the calculation of partial single-stage flash evaporation in a multicomponent system is:

$$x_i = \frac{\alpha_i}{1 + e \cdot (K_i - 1)}, \quad (1)$$

where α_i , x_i , and y_i represent the molar fractions of the i -th component in the feed, liquid, and vapor phases, respectively.

$e = \frac{G}{F}$ is the molar fraction of vapor (distillate yield) at the end of the flash evaporation process. To solve this, we define F as a certain function. Taking the derivative:

$$\delta F / \delta e = - \sum \frac{\alpha_i \cdot (K_i - 1)^2}{(1 + e \cdot (K_i - 1))^2} < 0 \quad (2)$$

The phase equilibrium constants are calculated using the equation:

$$K_i = P_i / P_t, \quad (3)$$

where P_i is the vapor pressure of component i , and P_{total} is the total system pressure.

Results and Discussion

The distillate fraction was determined using the bisection method with an accuracy of up to 0.00001 (Figure 2). The implementation of the bisection algorithm in the Pascal programming environment ensures high calculation speed and accuracy when solving problems related to phase equilibrium and the separation of multicomponent mixtures. Pascal is an effective tool for rapid testing and analysis in scientific research, as it does not require significant computational resources and provides sufficient precision for solving basic mathematical problems [15,16].

At the start of the program, the initial values were set as $e_1 = 0$ and $e_2 = 1$. Using the bisection method, the value of E is initially assigned as e_1 , and then recalculated as $e = (e_1 + e_2) / 2$. The algorithm checks whether the condition $abs(e_1 - e_2) < 0.00001$ is satisfied. If the condition is met, the current value of E is accepted. If not, the value f is updated using the formula: $f = f + \theta \cdot q / (1 + \theta \cdot q)$

Next, the condition $f > 0$ is evaluated. If true, $e_1 = E$ is set; otherwise, $e_2 = E$ is updated. The ramp-up time is also calculated within the Pascal environment using the program *m1* [17].

The developed model serves as a simplified yet functional tool for predicting phase behavior and distillate yield during the separation of gas condensate mixtures. To improve the reliability of the results, it is recommended to verify the model by comparing its output with

the results obtained from specialized simulators and to calibrate it using actual field data from gas condensate reservoirs [18].

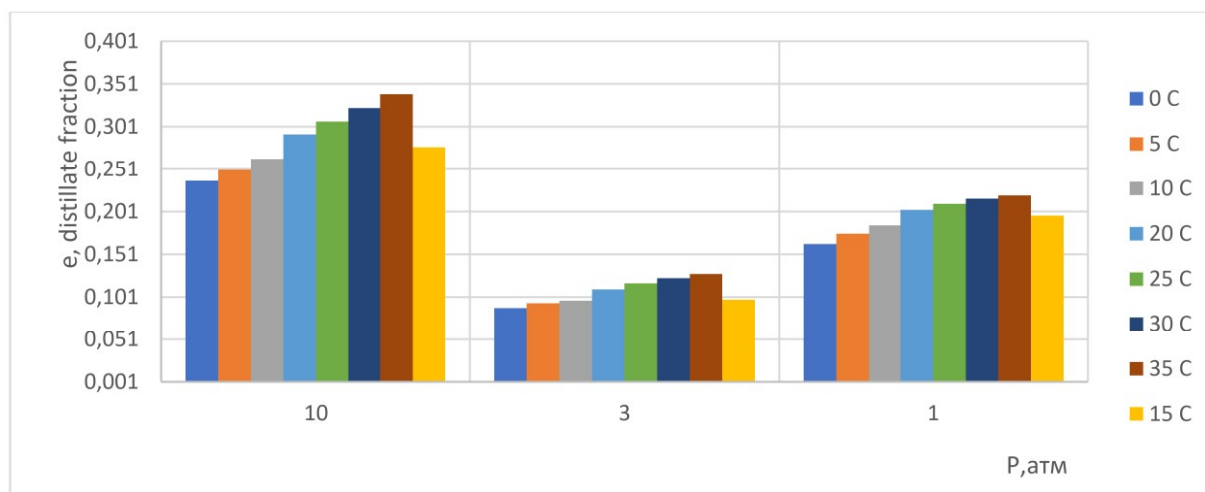


Figure 2 – Dependence of the distillate fraction on temperature

An analysis of the impact of thermobaric conditions on the separation process was conducted. It was established that an increase in temperature at pressures of 1, 3, and 10 MPa leads to a higher distillate fraction. This effect is attributed to the enhanced volatility of the components in the mixture and the intensification of evaporation processes. Elevated temperature facilitates the transition of light and medium-temperature fractions into the vapor phase, thereby increasing the distillate yield at each stage of separation. The most significant influence of temperature is observed in the early stages of separation under high pressure, where thermal effects notably affect phase equilibrium.

Table 1 – Findings of the single evaporation calculation

Temperature, °C	Separators	Distillate fraction	Molar fraction of the vapor phase $\sum(C1 + C2 + C3)$	Molar fraction of the liquid phase $\sum(C1 + C2 + C3)$
0	1	0.237	0.975	0.273
	2	0.088	0.911	0.211
	3	0.163	0.735	0.109
5	1	0.250	0.971	0.263
	2	0.094	0.894	0.197
	3	0.175	0.692	0.094
10	1	0.263	0.964	0.253
	2	0.097	0.874	0.183
	3	0.185	0.645	0.079
15	1	0.277	0.959	0.238
	2	0.098	0.404	0.066
	3	0.195	0.539	0.017
20	1	0.291	0.950	0.228

	2	0.110	0.828	0.156
	3	0.203	0.551	0.055
25	1	0.307	0.942	0.216
	2	0.117	0.801	0.138
	3	0.210	0.501	0.045
30	1	0.323	0.932	0.204
	2	0.123	0.768	0.126
	3	0.216	0.452	0.036
35	1	0.339	0.922	0.192
	2	0.128	0.738	0.112
	3	0.220	0.405	0.028

Table 1 indicate that an increase in temperature and a decrease in pressure lead to a reduction in the fraction of light hydrocarbons in the vapor phase and an increase in the fraction of heavy hydrocarbons. The optimal separation results, in terms of maximizing the extraction of target hydrocarbons C₅₊ and minimizing the loss of ethane with the gas, were achieved at a temperature of 35°C.

Conclusions

The proposed gas condensate separation model, utilizing the sequential separation method, represents an effective and accessible tool for engineering calculations in the stabilization of condensate. Despite limitations due to simplifications in the model and the lack of dynamic factor considerations, it is an important step in optimizing hydrocarbon mixture separation processes. Further development of the model, including its integration with more complex methods and the incorporation of dynamic parameters, will extend its application in both industry and scientific research. For the stabilization of gas condensate, single-stage, two-stage, and three-stage separation schemes can be employed. The choice of the optimal scheme depends on the concentration of light hydrocarbons in the condensate. When the concentration of light hydrocarbons is high, a multi-stage separation scheme is preferable, as it reduces the distillation fraction at each stage and minimizes the involvement of target hydrocarbons from the condensate in the vapor phase.

This study has chosen a three-stage separation scheme, characterized by simplicity in technology and low energy consumption. Based on the results, it is evident that as temperature increases and pressure decreases, the fraction of light hydrocarbons in the vapor decreases, while the fraction of heavy hydrocarbons increases. The best results were obtained at a temperature of 35°C.

To prevent the loss of light hydrocarbons with the vapor, it is recommended to mix them and subsequently send them to a distillation column for separation into methane, ethane, and heavier hydrocarbon fractions, which can be used as valuable petrochemical feedstock.

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ГАЗ КОНДЕНСАТЫН БӨЛУ КЕЗІНДЕГІ БІР БУЛАНУДЫ ЕСЕПТЕУ

Аңдатпа. Мақалада мұнай мен газ конденсатын тұрақтандыру арқылы ең ұшқыр көмірсутектерді (C₁–C₄) бөліп алудың артықшылықтары қарастырылған. Тұрақтандыру жеңіл фракциялардың булану кезіндегі шығынын 80%-ға дейін азайтып, Қарашығанақ мұнай-газ конденсат кен орнынан бастап мұнай өңдеу зауыттарына дейінгі аралықта жабдықтар мен құбырлардың коррозиясын болдырмайды.

Тиімді тұрақтандыру әдістеріне салыстырмалы талдау жүргізілді: үш сатылы бөлгіш жүйе, тұрақтандыру колоннасындағы айдау және олардың комбинациясы.

Фазалық тепе-теңдік константалары мен дистиллят үлестері Pascal бағдарламалық ортасында жүзеге асырылған жартылай бөлу әдісімен есептелді. Үш сатылы бөлудің оңтайлы параметрлері анықталды: бірінші саты — 1 МПа, 35 °С; екінші саты — 0.3 МПа,

35 °С; үшінші саты — 0.1 МПа, 35 °С. Бұл параметрлер тұрақтандырылған конденсаттың қаныққан бу қысымын 66.7 МПа-ға дейін төмендетуге мүмкіндік береді. Үш сатылы схема технологиялық қарапайымдылығымен және салыстырмалы түрде төмен капиталдық және пайдалану шығындарымен ерекшеленеді. Тұрақтандыру тиімділігін арттыру мақсатында екінші және үшінші сатылардың бу ағындарын біріктіріп, 11 торлы табақшасы бар ректификация колоннасына бағыттау ұсынылады. Колоннаның оңтайландырылған жұмыс режимі (3.6 МПа, үстіңгі температурасы 26.5 °С, төменгі температурасы 81 °С) метан, этан және ауыр көмірсутектер (C₃₊) фракцияларын тиімді бөлуге жағдай жасайды. Бұл компоненттер тұрақтандырылған конденсат ағынына қайтарылады. Метан-этан қоспасы мұнай-химия өнеркәсібіне болашағы зор шикізат ретінде қарастырылады.

Кілт сөздер. Газ конденсатын тұрақтандыру, бір реттік булану, жеңіл көміртекті қосылыстар, үш сатылы сепарация, мұнай-химия шикізаты.

РАСЧЕТ ОДНОКРАТНОГО ИСПАРЕНИЯ ПРИ РАЗДЕЛЕНИИ ГАЗОВОГО КОНДЕНСАТА

Аннотация. В данной статье рассмотрены преимущества стабилизации нефти и газового конденсата с целью извлечения наиболее летучих углеводородов (C₁-C₄). Стабилизация позволяет снизить потери легких фракций на испарение до 80 % и предотвратить коррозию оборудования и трубопроводов на всем протяжении от Карачаганакского нефтегазоконденсатного месторождения до нефтеперерабатывающих заводов. Основные характеристики газового конденсата месторождения: плотность 782.38 кг/м³, содержание C₅₊ 8.01 % (мол.) [1].

В работе проведен сравнительный анализ эффективных методов стабилизации, а именно: трехступенчатое разделение, дистилляция в стабилизационной колонне и их комбинирование.

Расчет констант фазового равновесия и определение доли дистиллята для газового конденсата осуществлены с использованием алгоритма половинного деления, реализованного в программной среде Pascal. На основе полученных расчетов определены оптимальные параметры трехступенчатого разделения: первая ступень – давление 1 МПа, температура 35 °С; вторая ступень – давление 0.3 МПа, температура 35°С; третья ступень – давление 0.1 МПа, температура 35 °С. Данные параметры позволяют снизить давление насыщенных паров стабилизированного конденсата до 66.7 МПа. Отмечены преимущества трехступенчатой схемы разделения, такие как простота технологической реализации и относительно низкие капитальные и эксплуатационные затраты. Для повышения эффективности стабилизации предлагается объединить потоки паров со второй и третьей ступеней сепарации и направить их в ректификационную колонну, оснащенную 11 тарелками сетчатого типа. Оптимизирован режим работы колонны: давление 3.6 МПа, температура верха 26.5 °С, температура низа 81 °С. В колонне происходит разделение на фракции метана, этана и более тяжелые углеводороды (C₃₊), которые возвращаются в поток стабилизированного конденсата. Фракция метан-этановой смеси рассматривается в качестве перспективного сырья для нефтехимической промышленности [2].

Ключевые слова. Стабилизация газоконденсата, однократное испарение, легкие углеводные соединения, трехступенчатая сепарация, нефтехимическое сырье.