Machinery & Energetics
Vol. 15, No. 1. 2024

Journal homepage:
https://technicalscience.com.ua/en

UDC 622.2:004
DOI: 10.31548/machinery/1.2024.33

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Integration of advanced technologies to improve the efficiency of gas condensate field development

Abstract. In the context of constantly growing global energy demand and rapid changes in the energy sector, the study and implementation of advanced technologies in the development of gas condensate fields is of critical importance. The purpose of this study is to investigate methods to increase the efficiency of production and sustainable use of energy resources by optimising the development of gas condensate fields using advanced technologies. The methods used include analytical method, classification, functional method, statistical method, synthesis. Within the framework of this study, the technological aspects of using wells of the Altyguyi gas condensate field were investigated and extensive laboratory and field analyses were conducted aimed at the correct implementation of the double injection method for simultaneous extraction of gas from one reservoir and oil from another, with an emphasis on their contribution to the development of wells through this approach. The paper also considers aspects of operation and technology, including hydrodynamic and thermohydrodynamic studies, when analysing well designs considering compatibility intervals and mining and geological drilling conditions, based on predictive curves of reservoir pressure and rock fracture pressure. As a result of the analyses, studies and calculations, the implementation of the method of intensification of gas condensate field production using the oil and gas approach of dual injection in one well was substantiated. This approach is focused on reducing capital investments and accelerating the development process. The practical significance of this research lies in the development and implementation of innovative technologies to optimise the production processes of gas condensate fields, which contributes to improving the efficiency of hydrocarbon production and promotes the sustainable use of energy resources

Keywords: sustainable use; optimisation of processes; double injection; prognostic curves; production intensification

INTRODUCTION

The study of technologies for the development of gas condensate fields and their optimisation through the integration of advanced methods is an integral aspect in the context of dynamic changes in the energy sector and the ever-growing global demand for energy. Efficient use of gas condensate resources is becoming a key element for ensuring energy sustainability and promoting sustainable development. Approaches such as double injection, hydrodynamic research, and the integration of innovative technologies not only contribute to improving production efficiency, but also reduce capital investment and accelerate the development process, which is critically important in the context of the current challenges of the energy industry and rapid changes in the global energy paradigm.

The research focuses on identifying and solving complex technological and organisational issues related to the development of gas condensate fields. These difficulties include not only technical aspects, such as optimising the processes of extraction, processing, and transportation of gas condensate, but also organisational issues related to project management, interaction with stakeholders, and ensuring compliance with regulatory requirements and environmental standards. Solving these problems requires an integrated approach that includes both scientific research

Article's History: Received: 30.10.2023; Revised: 19.01.2024; Accepted: 28.02.2024.

Suggested Citation:
Deryaev, A. (2024). Integration of advanced technologies to improve the efficiency of gas condensate field development. *Machinery & Energetics,* 15(1), 33-42. doi: 10.31548/machinery/1.2024.33.

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and practical expertise, and consideration of economic and social factors.

A. Deryaev (2023a) considers in detail the effectiveness of the double injection method in gas condensate fields, analysing its pros and cons in detail and offering recommendations for optimising its application. The study does not address alternative methods for optimising the production processes of gas condensate fields, which may limit the understanding of possible effective strategies. V.G. Golubev *et al.* (2020) consider the technological aspects of wells using the example of a gas condensate field, paying attention to the influence of mining and geological conditions on the choice of well designs. However, due attention is not paid to the diversity of geological conditions, which may reduce the generality of the results obtained.

A study conducted by B.R. Pulatov (2021) emphasises the hydrodynamic and thermohydrodynamic aspects of the exploration of gas condensate fields, substantiating their importance for determining optimal solutions in the development process. The study does not consider thermohydrodynamic aspects sufficiently, which may be key in adapting technologies to various thermal conditions of deposits. R. Al Dhaif *et al.* (2022) argue that forecasting of surface oil flows in unstable oil and gas condensate reservoirs using artificial intelligence methods is an advanced approach with significant potential in the modern oil and gas industry. This method is based on the use of artificial intelligence algorithms such as machine learning and neural networks to analyse complex and multidimensional data related to oil and gas fields. One of the advantages of using artificial intelligence methods in forecasting of oil flow rates is their ability to identify complex relationships between various parameters and factors affecting production. This includes not only the geological and physico-chemical characteristics of deposits, but also dynamic changes in production conditions (Kondrat & Matiishyn, 2023).

The purpose of this study is to explore the possibilities of increasing the efficiency of production and sustainable use of energy resources through optimising the development of gas condensate fields using advanced technologies.

MATERIALS AND METHODS

In the study conducted on the territory of the western region of Turkmenistan, the main attention was paid to two deposits: Altyguyi and Korpedje. Data from several wells in each of these fields were analysed. During the study, information was collected on the geological characteristics of deposits, gas composition, and data on temperature and pressure in wells. These data were used to assess potential gas condensate reserves at the sites under consideration.

The analytical method helped in a detailed review of the existing production parameters of gas condensate fields, which helped to identify key factors affecting the efficiency of development processes. This method contributed to the development of optimisation strategies and became the basis for making informed decisions on the introduction of advanced technologies aimed at increasing the efficiency and sustainability of the use of energy resources. Comprehensive data studies were carried out using the statistical method, which identified trends and patterns in the production of gas condensate fields. These statistical patterns helped to assess the current efficiency of processes and predict possible development scenarios, which significantly enriched the knowledge base and provided the basis for developing strategies to improve the extraction and sustainable use of energy resources.

Using the functional method, the main functions and parameters affecting the efficiency of the development of gas condensate fields were identified. This method helped to systematise mining processes and identify optimal strategies for the introduction of advanced technologies. The results obtained using the functional method provided the basis for the development of innovative solutions aimed at optimising processes and increasing the sustainability of the use of energy resources in the context of gas condensate fields.

The deduction method helped in the systematic identification of general patterns and principles underlying the efficient production of gas condensate fields. This method helped formulate the fundamental principles of optimising development processes by logically establishing causal relationships. Employing the deduction method yielded a deeper understanding of the key factors impacting production efficiency and facilitated the development of strategies promoting the sustainable use of energy resources in gas condensate production.

By applying the synthesis method, various aspects of the development of gas condensate fields were combined into a single whole. This method provided a comprehensive view of the relationship between technological, environmental, and economic factors in the mining process. The results of the synthesis revealed optimal solutions that ensure not only increased efficiency, but also compliance with the principles of sustainable use of energy resources in the development of gas condensate fields.

The classification method helped in the systematisation and grouping of various factors affecting the development of gas condensate fields. This method identified key categories and parameters, which made it easier to assess the importance of each element in the context of optimisation. The results of the classification method provided the basis for developing individual strategies for the introduction of advanced technologies, depending on the specifics of each group of factors, thereby contributing to increasing the efficiency and sustainability of the use of energy resources in the development of gas condensate fields.

Using the induction method, general patterns were derived based on observations and specific cases of the development of gas condensate fields. This method allowed identifying the main trends and successful practices that can be applied in a broad context. The insights gained through the induction method pave the way for the development of general guidelines for optimizing gas condensate field development, incorporating advanced technologies. As such, this method plays a crucial role in establishing overarching strategies to improve efficiency and sustainability in the use of energy resources during gas condensate production.

The following equation was used in the study (1-5):

$$T_{sep} = T_{ent.} - \Delta T_{thr.} - \Delta T_{TO}, \quad (1)$$

where $T_{ent.}$ – gas temperature at the inlet to the gas processing point (GPP); $\Delta T_{thr.}$ – throttle temperature drop due to the Joule Thompson effect; ΔT_{TO} – gas temperature drop in the heat exchanger.

$$\Delta T_{thr.} = \frac{\Delta P_{thr.}}{\varepsilon}, \quad (2)$$

where $\Delta P_{thr.}$ – throttle pressure drop (MPa) and Joule-Thompson coefficient (ε): $\varepsilon = 0.27$ MPa/°C (assumed based on throttling conditions).

$$\Delta T_{thr.} = 2\Delta T_{thr.}, \quad (3)$$

$$P_{ent.cr.} = P_{req.} + P_{thr.}, \quad (4)$$

where $P_{req.}$ – outlet pressure of the gas processing plant (GPP).

$$P_{req} = P_{ter.} + \Delta P_{g.p.}, \quad (5)$$

where $P_{ter.}$ – final pressure allowed under gas supply conditions, equivalent to 5.6 MPa.

The key benefit of these calculations lies in their ability to illuminate the impact of various factors on gas condensate field development processes.

RESULTS

A full range of studies and systematic measurements are carried out at the gas condensate fields of Turkmenistan. These activities are designed to complement the main complex of hydrodynamic and field geophysical studies and measurements. They have received the approval of the relevant authorities and strictly comply with the requirements set out in the approved project document for the development of the field. This complex of studies and measurements covers various important aspects, including the rapid detection of wells that may be sources of underground leaks and interplastic flows. Implementing such a comprehensive approach is vital for achieving the sustainable and safe development of these gas condensate fields.

Table 1 comprehensively details the operational and technical specifications of Altyguyi's productive oil wells. It is noteworthy that the flow rates of 24 fountain wells in the field range from 82 to 6 tonnes per day, the watercut varies from 1% to 30%. It is worth emphasising that the watercut in three of these wells (designated as wells 7, 16, and 18) is 73%, 71%, and 77%, respectively. The gas factor for these wells ranges from 205 to 1129 m^3 per tonne, and the solidification temperature of the oil ranges from 36 to 37°C. These detailed characteristics provide valuable information about the operational characteristics and composition of productive wells of the Altyguyi field, which are necessary for effective field management and production optimisation.

Table 1. Key operational and technical details of Altyguyi's high-performing wells

No. of well	Work method	Horizon	Borehole, m	Fitting diameter, mm	Gas supply depth, m	Note
21	fountain	PC-8	4007	5	2200	
3	fountain/gas lift	PC-9	3757	4		
4	fountain	PC-9	3770	8		
7	fountain	PC-9	3758	5		
10	fountain	PC-9	3674	6		
11	fountain	PC-9	3868	6		
12	fountain	PC-9	3740	8		
16	fountain/gas lift	PC-9	3875	5		Punch 2000 m
17	fountain	PC-9	3860	8		
18	fountain	PC-9	3905	4		
19	fountain	PC-9	3910	8		
24	fountain	PC-9	3751	8		
51	fountain/gas lift	PC-9	3685	5		Punch 2000 m
52	gas lift	PC-9	3685	6	2200	Punch 2000 m
102	fountain	PC-9	3727	6		
104	fountain	PC-9	3760	4		
105	fountain	PC-9	3860	8		
106	fountain	PC-9	3810	5		
107	fountain	PC-9	3885	5		
108	fountain	PC-9	3829	6		
110	fountain	PC-9	3820	4		

Continued Table 1.

No. of well	Work method	Horizon	Borehole, m	Fitting diameter, mm	Gas supply depth, m	Note
111	fountain	PC-9	3880	8		
112	fountain	PC-9	3771	4		
113	fountain	PC-9	3705	8		
114	fountain	PC-9	3700	6		

Note: PC – pumping and compressor equipment
Source: developed by the author based on A.R. Deryaev (2023b)

In 2011, two wells numbered 3 and 51 underwent significant changes in operation as a result of switching to gas lift mode. However, in 2014, these wells were switched to semi-spontaneous operation, which led to the termination of the supply of working agent. As a result, these wells are now operating in fountain mode (Deryaev, 2023c). During the use of the gas lift method, a number of notable transformations have occurred, marking a dynamic evolution over time. A gradual decline in annular pressure caused gas to come out of the oil, while the amount of dissolved gas in the extracted products simultaneously increased. These developments necessitated a shift from gas lift to fountain operation in the wells (Sahu *et al.*, 2021).

Due to the decrease in reservoir pressure in productive formations, it becomes necessary to carry out measures to restore gas supply, which necessitates a return to the gas lift method of operation. This adaptive strategy is of paramount importance to ensure the sustainable efficiency and productivity of these wells. Due to the flexibility of operational methodologies, the goal is to optimise the production process in direct response to fluid and changing conditions within the reservoir. This adaptive approach serves as a strategic imperative, ensuring that mining operations remain finely tuned and aligned with the ever-changing dynamics of the reservoir, which ultimately supports the overall efficiency of the mining process. The field currently boasts 52 operational wells. In line with the field's meticulous development plan, a comprehensive evaluation is being conducted to determine if all existing naturally flowing wells can be converted to gas lift operation. This potential change is being meticulously evaluated with the primary objective of boosting industry-wide productivity and efficiency (Syed *et al.*, 2022). Such a step will not only increase operational efficiency, but will also meet the changing needs and requirements of the field's development strategy.

Table 2 provides a detailed overview of proposed strategies for the systematic transition to gas lift operation in the field's existing flowing wells. The subtleties of this gas lift method are revealed as a well-thought-out operational paradigm strategically focused on improving the efficiency of production at the Altyguyi field. In this innovative gas lift method, a decisive shift in operation occurs in the depth range of 2000-2200 m. Here, a carefully selected working agent, often in the form of a heated gas, becomes a catalyst for improving extraction dynamics. The introduction of this agent is carefully controlled using specialised gas lift valves temporarily installed on the drilling site with precision (Giglio *et al.*, 2021). This thoughtful operational plan is not just a procedural adjustment, but represents a fundamental aspect of a comprehensive field development strategy. A special infrastructure has been carefully created to ensure the smooth execution of gas lift operations at the field. This infrastructure is designed in such a way as to ensure uninterrupted and efficient gas supply to gas lift wells. The gas supplied at an operating pressure of 70 to 85 kgf/cm^2 passes through specialised gas compressor lines to reach its destination. It is important to note that each well within the framework of gas lift operation requires an average gas consumption of about 15 thousand m^3/day. This infrastructure is not just a logistical basis; it is an integral component that ensures the viability and sustainability of the gas lift method throughout the field. The significance of this operational transition goes beyond just improving efficiency. This is a strategic step that meets the changing requirements of field management, optimising production volumes while maintaining environmental considerations. The careful implementation of the gas lift method, combined with a reliable infrastructure supporting its implementation, is evidence of the field's commitment to advanced technologies and best practices in the field of oil production (Borj *et al.*, 2024). As the industry continues to evolve, these strategic operational shifts highlight the adaptive nature of resource management, ensuring that the Altyguyi field remains at the forefront of efficient and sustainable energy production.

Table 2. Proposed option for conversion of flowing wells at the Altyguyi field to gas lift operation mode

Indicators	Unit of measurement	2022	2023	2024	2025	2026	2027
Oil production	thousand tonnes						
Liquid extraction	thousand tonnes						
Gas related resources	million m^3						
Conversion of wells to gas lift method	well		5	6	7		

Continued Table 2.

Indicators	Unit of measurement	2022	2023	2024	2025	2026	2027
Fund of gas lift wells that will be put into operation by the end of the year	well	1	6	12	19	19	19
Average oil flow rate of operating wells	t/day						
Liquid	t/day						
Water restriction	%						
Gas resource required for the gas lift	million m^3	1.9	5.9	30.2	32.3	43.1	41.7

Source: developed by the author based on A.R. Deryaev (2023b)

The ideal flow rate is crucial for the most efficient operation of the gas lift system, which requires a reduction in specific consumption. For optimal flow rate, the gas lift needs to be submerged as deeply as possible below the dynamic fluid level. Ideally, the lift's length should closely match the well's depth. In scenarios where maximum flow rate is required while minimising specific flow, a relative immersion value of $\xi = 0.5$ is ideal. For optimal efficiency, a relative maximum flow rate of $\xi = 0.6$ is employed (Rodrigues *et al.*, 2021). Efficiently operated gas lift wells need careful optimisation using proven techniques. Based on calculations, gas lift wells where the gas is injected at a depth between 2300 and 2500 meters, specific operating pressures $P_{work} = 6.4$, 7.4, and 8.4 MPa are considered feasible. For wells with gas receivers at depths from 3000 to 3500 m, the standard operating pressures range from 10 to 12 MPa. Gas condensate fields benefit significantly from the implementation of closed-cycle compressor gas lift systems (Wang *et al.*, 2022). To effectively support gas lift operations and guarantee export-quality gas delivery to the pipeline, this system necessitates the incorporation of advanced gas treatment technologies. Such an integrated approach not only improves operational efficiency, but also meets environmental and safety standards, contributing to the overall success of the gas condensate field development.

The Altyguyi field's wellhead infrastructure for product collection and processing is seamlessly integrated with the adjacent Korpedje field's systems. This compatibility allows for a unified and standardized approach to handling products from both regions, leading to improved operational efficiency and enhanced resource utilization. Figure 1 illustrates the Altyguyi field's gas condensate collection and processing technology. The collected gas and condensate from the Altyguyi field's wells are directed through pipelines to sophisticated measuring equipment. Subsequently, they are transported via collectors to the Korpedje field's gas treatment plant for initial processing. This interconnected system simplifies the transportation and processing of gas condensate, optimising the use of resources and contributing to increased overall operational efficiency.

As a sample of gas condensate field development technology in the energy sector, a study of a gas field in the Western region of Turkmenistan was conducted. Part of this is the inspection of production wells, collection systems, treatment systems, and compression of produced gas. The purpose is to assess the practicality and necessity of potential modifications or reconstruction in the context of future field development projects. Such an assessment is crucial to ensure that the field's energy infrastructure remains adaptive and efficient in response to changing operational requirements and environmental considerations. Such a far-sighted approach helps to maintain the sustainability and competitiveness of the operation of gas condensate fields in the long term.

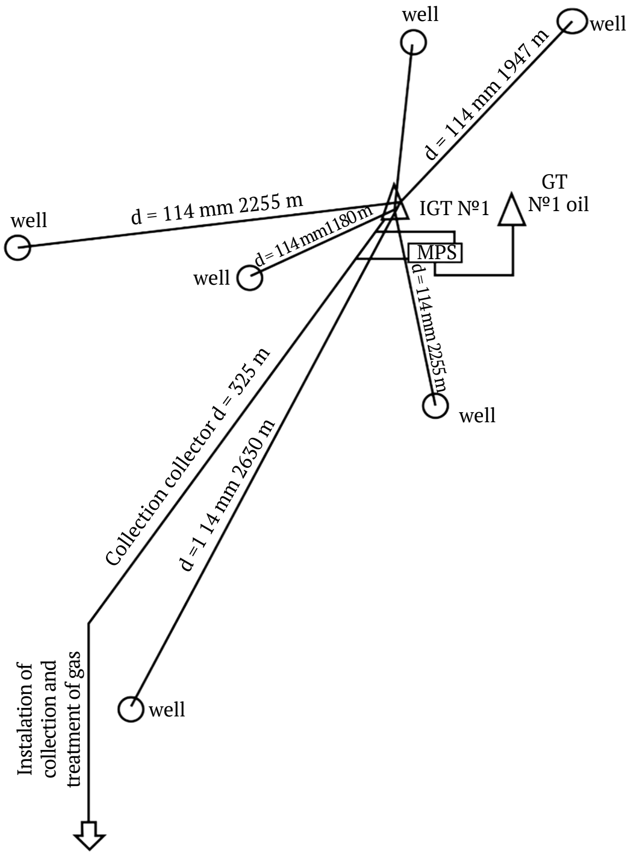

Figure 1. ltyguyi field gas condensate well collection and processing system

Note: IGT – industrial gas turbine, MPS – multiprocessor system, GT – gas turbine

Source: developed by the author based on A.R. Deryaev (2023b)

The compressor station (CS) plays a crucial role in ensuring the efficient operation of the gas processing complex (Zhou *et al.*, 2021). The main function is to compress the associated gas when it enters the station via a gas pipeline. This process is carried out in three separate compression stages. During compression, the gas undergoes transformations as its pressure rises from 0.3 MPa to 7.5 MPa. This compression procedure is crucial to ensure the flow and utilisation of the appropriate gas inside the installation. The CS is also responsible for the compression of associated gas entering the station from several oil and gas collection points, namely, a conventional pumping compressor station 1 and 2 located near the respective fields. These integrated gas pipelines combine several associated gas sources, consolidating their flows and subjecting them to the necessary compression. The CS also compresses natural gas directly produced at the gas condensate field. This gas arrives at the station through a dedicated combined gas pipeline, meticulously connected to the corresponding group measuring equipment (GME) for accurate flow measurement. This compression operation ensures that the natural gas from the field is under sufficient pressure for further processing and transportation, which corresponds to the overall operational objectives of the facility. The multifaceted functions of the compressor station are an integral part of the uninterrupted processing and transportation of various gas flows, which contributes to improving the overall efficiency and productivity of the gas processing complex.

The CS has a number of technical and technological characteristics necessary for its effective operation. The CS is equipped with two separate installations, each of which has cooling systems responsible for the first and second stages of associated gas compression. The CS is also responsible for compressing the corresponding gas entering the station from the oil and gas collection stations of the production pumping station 1 and 2. This intermediate pressure serves as the inlet pressure for the subsequent final or third compression stage. To guarantee optimal efficiency by keeping the equipment within its operating temperature range, cooling systems are indispensable. The compressor station features three dedicated units for the third compression stage: one for associated gas and two for natural gas directly from the pipeline. This design enables efficient and separate compression of different gas streams, contributing to optimized operations.

A noteworthy feature of the CS is its low-temperature mechanical cooling system. This system employs steam compression technology with a refrigerant, often freon, to achieve low-temperature condensation for cooling purposes. This cooling system is crucial to maintain the proper gas temperature, prevent overheating, and protect the integrity of the compressor station equipment. Together, these technical and technological characteristics allow the CS to effectively manage and process associated and natural gas flows, while maintaining the necessary operating conditions and equipment integrity. The cooling systems and compression stages are carefully designed to improve the overall efficiency of the gas processing complex. The gas resources that can be efficiently shipped to consumers with a given gas quality exactly correspond to the annual design capacity of the CS. A constant pressure is maintained at the inlet of the CS by utilizing two distinct gas streams, which helps preserve equilibrium (Moldabayeva *et al.*, 2021).

The integrated gas treatment plant at the current development stage faces a unique challenge: maintaining the required inlet pressure while guaranteeing export gas quality. This pressure ensures the gas meets the specified water and hydrocarbon dew point parameters outlined in the gas supply contract, crucial for reliable and compliant gas delivery to consumers. The GPP plays a key role in achieving these standards and maintaining stable export gas quality. However, a current study of the GPP's operational parameters reveals insufficient reservoir pressure at the inlet compared to the original design plan. This pressure shortfall impacts the overall efficiency of the gas cooling process, which utilizes low-temperature gas separation technology with regenerative heat exchange. It's crucial to recognize that the specific heat exchanger employed plays a significant role in the cooling process efficiency. This dependence is directly linked to the heat exchanger's design and the surface area of its heat exchange plates. In simpler terms, the choice and characteristics of the heat exchanger directly impact the gas cooling process efficiency.

Integrated heat exchangers within the GPP are crucial for this cooling process, significantly lowering the gas temperature before it enters the low-temperature separator. This reduction is achieved using a method known as regenerative heat transfer and results in a temperature reduction of almost half compared to the traditional Joule-Thompson throttling effect. The introduction of these state-of-the-art heat exchangers underlines the plant's commitment to improve cooling efficiency and maintain the necessary quality standards for the processed gas. Using equation (1), the required operating temperature of gas separation was calculated, especially in a low-temperature separator. The decrease in throttle temperature due to the Joule-Thompson effect is calculated using equation (2). Based on operational data, equation (3) describes the decrease in gas temperature occurring within the heat exchanger. The reference pressure at the inlet of the integrated gas treatment plant, where the gas is conditioned to meet the required specifications, depends on two factors. Then, a specific ratio is evaluated based on equation (4). Then the estimated pressure at the pipeline's end (obtained from equation (5)) and the total pressure losses throughout the pipeline are considered.

Based on the calculated ratios, obtaining conditioned gas with a specific water dew point requires $T_{d.w.} = 0°C$, the required pressure drop at the GPP installation is approximately DR~3 MPa in the summer months and about DR~1.5-2 MPa in the winter months. To meet these conditions, the pressure at the inlet to the GPP should be approximately $P_{ent.}$~9.5 MPa in summer and $P_{ent.}$~8.5 MPa in winter. To ensure the inclusion of suitable high-pressure gas resources in the current field development project, this document defines the necessary criteria. These resources must be treatable to meet the specified GPP conditions and align with the calculated inlet pressure values

(Leontidis *et al.*, 2023). To ensure export-quality gas is delivered even with the anticipated decrease in high-pressure gas supplies, the gas compressor station needs to maintain operation in gas treatment modes. To address this critical challenge, the immediate construction of a booster compressor station is essential. It's important to note that gas lift wells receive their supply through dedicated gas pipelines connected to the main pipeline. These injection lines operate at pressures from 6.2 to 11 MPa, providing gas supply to gas lift wells. Effective operation of gas lift wells requires optimisation based on proven techniques. Calculations show that for gas lift wells with gas injection points at depths from 2300 to 2500 m, the recommended operating pressures are $P_r = 6.4$, 7.4, and 8.4 MPa. For wells with a gas inlet depth of 3000 to 3500 m, the operating pressure should be in the range of 10 to 12 MPa.

DISCUSSION

The integration of advanced technologies into the development of gas condensate fields represents a key aspect in the modern oil and gas industry. This topic is highly relevant, since oil and gas companies face the constant challenge of increasing production efficiency under conditions when gas condensate fields present complex technological and engineering tasks. The integration of advanced technologies included a variety of innovations, ranging from the use of modern methods of geophysical research and seismic analytics to accurately determine the structure of the field, to the introduction of automated well management systems and the use of advanced production methods such as hydraulic fracturing. One of the important aspects of the study was to reduce the environmental impact of hydrocarbon production. The use of advanced technologies allowed for more precise control of production processes, reducing the risks of leaks and minimising the impact on the environment (Shmandii *et al.*, 2022).

According to S. Matkivskyi *et al.* (2021), methods for extracting hydrocarbon resources are evolving rapidly, investigating the impact of CO_2 injection rates on water pressure system behavior during gas condensate field development is becoming increasingly crucial. The growing popularity of CO_2 injection to enhance gas condensate production necessitates a thorough understanding of its effects on the field's water management system. (Dzhalalov *et al.*, 2021). One of the key aspects of the study under discussion is the assessment of the effect of different injection rates of CO_2 on hydrodynamic processes in the water pressure system. This includes studying pressure changes, water flow rates, and interactions with the reservoir and adjacent gas condensate layers. The data obtained can significantly influence the development of optimal CO_2 injection strategies that ensure efficient extraction of gas condensates with minimal negative impacts on the water supply. These data are consistent with the theses given in the previous section. This study represents an important step towards improving the efficiency of gas condensate production, while emphasising the importance of balancing technological advantages and environmental sustainability of water supply.

Referring to the definition of L. Jia *et al.* (2021), the application of changing the wettability of gas to improve the efficiency of methane drainage is an innovative approach that can significantly improve the efficiency of natural gas production processes. This method uses the possibility of changing the interaction of gas with the surface of a porous medium, which contributes to more efficient displacement and drainage of methane from gas fields. A practical example of the application of this method may include the use of modified surfactants or coatings capable of affecting the wettability of gas in porous formations. Such technologies can be applied in field conditions where conventional methods of methane extraction face limitations. For example, changing the wettability can increase the permeability of rocks, which, in turn, will reduce the resistance to gas flow and increase its yield (Tileuberdi *et al.*, 2021). It should be noted that when implementing such innovative methods, it is important to consider potential challenges. These include the need for thorough testing and adaptation to specific geological and technological features of the deposit, and an assessment of the environmental consequences of the impact of new substances on the environment. Effective management and optimisation of these technologies require a systematic approach and balanced attention to technical and environmental aspects.

A.R.B. Abad *et al.* (2021) have shown that the use of hybrid machine learning algorithms for predicting condensate viscosity in the bottomhole zone of gas condensate deposits is a promising approach aimed at improving the accuracy and reliability of estimates in conditions of complex geological formations. These hybrid algorithms combine the advantages of various machine learning methods, which makes it possible to better understand a variety of factors affecting the viscosity of condensate. One of the key advantages of hybrid algorithms is their ability to process large amounts of data, including a variety of formation parameters and mining conditions. This is especially important for gas condensate fields, where the complexity of geological structures and variable operating conditions can significantly affect the viscosity of condensate. It can be agreed with this view that successful implementation of hybrid algorithms requires good quality training data and constant updating of models to reflect changes in mining conditions. Such an approach to predicting condensate viscosity can significantly reduce time and resource costs in the production process and ensure more efficient management of gas condensate fields.

As noted by M.Z. Kamali *et al.* (2022), forecasting of the permeability of inhomogeneous carbonate gas condensate reservoirs using a group data processing method is a significant step in the field of accurate modelling and management of hydrocarbon production. Carbonate gas condensate reservoirs have a complex structure and heterogeneity, which complicates the prediction of their permeability, an important parameter for optimising production. The group data processing method is an innovative approach that allows considering groups of variables and dependencies between them when predicting permeability. This method can efficiently process large amounts of data, including various reservoir characteristics, geological parameters, and mining conditions. The use of the group method in predicting the permeability of carbonate gas condensate reservoirs can improve the accuracy of forecasts by considering many factors affecting this parameter (Ismailova *et al.*, 2021). It also provides the ability to adapt to changes in the geological structure and operating conditions, which is key to successful production management over time. Analysing the results and conclusions obtained, it is necessary to have high-quality and detailed data on the geological characteristics of the deposit for effective implementation. The application of the group data processing method in predicting the permeability of carbonate gas condensate reservoirs is a promising tool for improving production strategies and optimising the operation of deposits.

J. Tongwen *et al.* (2021) determined that the development of a three-element mechanism for cyclic injection of gas into condensate-gas formations represents an innovative approach to optimising the extraction of hydrocarbons from complex formations. This mechanism is based on the cyclic introduction of gas into the reservoir and its subsequent extraction, which contributes to the efficient production of condensate and gas. Such a method can provide better control of production processes and increase oil recovery, especially in conditions where conventional methods are ineffective. A new method of increasing condensate oil recovery, associated with a three-element mechanism of cyclic gas injection, provides an opportunity to optimise reservoir pressures and control the migration of hydrocarbons (Matkivskyi & Kondrat, 2023). This is especially true for condensate and gas fields, where proper pressure balancing can significantly increase the volume of extracted resources.

In addition, the successful implementation of this three-element mechanism requires a detailed study of the geological and physico-chemical properties of the deposit and the supporting infrastructure. The new method of condensate extraction through cyclic gas injection represents a promising way to optimise hydrocarbon production and can make a significant contribution to the sustainable and efficient use of energy resources.

CONCLUSIONS

The study investigated how integrating advanced technologies can improve the efficiency of developing gas condensate fields. One key finding is that using innovative methods to optimize production is crucial, as demonstrated by analyzing the technological aspects of well operation at the Altyguyi gas condensate field.

Utilizing gas lift appears to be a promising approach for improving the efficiency of hydrocarbon extraction. This method provides the possibility of effective pressure control and improved extraction of oil and gas, especially in gas condensate fields. Studies of hydrodynamic and thermohydrodynamic provide a deeper understanding of the impact of gas lift on the characteristics of wells and the field as a whole. This provides the necessary basis for the optimal choice of gas lift system parameters, considering the features of geological conditions.

Operational and technological aspects of hydrodynamic and thermohydrodynamic studies also make a significant contribution to the optimisation of field development. The analysis of well designs, considering the mining and geological conditions of drilling, opens up opportunities for improving processes. Data analysis allowed assessing the current state and efficiency of well operation, which is important for optimising hydrocarbon production processes. The results of the study highlighted the importance of further improving technological solutions and maintenance methods to increase the durability and productivity of wells.

An important result of the study is the development of intensification of a gas condensate field using oil and gas dual completion method with one well. This approach, the first in world practice, is focused on reducing capital investments and accelerating the development of deposits, which represents a significant contribution to the energy industry. This study not only expands the scientific understanding of the technological aspects of gas condensate field production, but also provides practical recommendations for integrating advanced technologies in order to increase efficiency and sustainable use of energy resources.

A complete understanding necessitates further research on the influence of various gas lift system parameters on the effectiveness of well conversion to gas lift. This research should also encompass a long-term analysis of the impact of gas lift on field production.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

None.

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Інтеграція передових технологій для покращення ефективності розроблення газоконденсатних родовищ

Анотація. В умовах постійно зростаючого світового попиту на енергію та стрімких змін в енергетичному секторі, вивчення та впровадження передових технологій у розробку газоконденсатних родовищ набуває критичного значення. Мета даної роботи полягає в дослідженні методів збільшення ефективності видобутку та сталого використання енергетичних ресурсів шляхом оптимізації процесів розроблення газоконденсатних родовищ з використанням передових технологій. Серед використаних методів слід відзначити аналітичний метод, метод класифікації, функціональний метод, статистичний метод, метод синтезу. У рамках цього дослідження вивчено технологічні аспекти використання свердловин Алтигуїнського газоконденсатного родовища, проведено широкі лабораторні та промислові дослідження, спрямовані на правильну реалізацію методу подвійного закачування для одночасного видобутку газу з одного пласта та нафти з іншого, з акцентом на їхній внесок у розробку свердловин за допомогою цього підходу. У роботі також розглянуто аспекти експлуатації та технології, включно з гідродинамічними і термогідродинамічними дослідженнями, під час аналізу конструкцій свердловин з урахуванням інтервалів сумісності та гірничо-геологічних умов буріння, з основою на прогностичних кривих пластового тиску і тиску руйнування гірських порід. У результаті проведених аналізів, досліджень і розрахунків обґрунтовано впровадження методу інтенсифікації видобутку газоконденсатного родовища з використанням нафтогазового підходу подвійного закачування в одній свердловині. Цей підхід орієнтований на скорочення капітальних вкладень і прискорення процесу розвитку. Практичне значення цього дослідження полягає в розробці та впровадженні інноваційних технологій для оптимізації процесів видобутку газоконденсатних родовищ, що сприяє підвищенню ефективності видобутку вуглеводнів, а також сталому використанню енергетичних ресурсів у сучасній енергетиці

Ключові слова: стале використання; оптимізація процесів; подвійне закачування; прогностичні криві; інтенсифікація видобутку