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THE INFLUENCE OF NITROGEN INJECTION DURATION AT THE INITIAL GAS-WATER CONTACT ON THE GAS RECOVERY FACTOR

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This paper reports a study that employed a digital three-dimensional model of the gas condensate reservoir to investigate the process of nitrogen injection at the boundary of initial gas-water contact at different values of the injection duration. The calculations were performed for 5, 6, 8, 10, 12 and 14 months injection duration. Based on the modeling results, it was found that increasing the duration of the nitrogen injection decreases the operation time of production wells until the breakthrough of non-hydrocarbon gas. Based on the analysis of the technological indicators of reservoir development, it was established that the introduction of technology of the nitrogen injection into a reservoir ensures a reduction in the volume of reservoir water production. The cumulative water production at the time of nitrogen breakthrough to the production wells at the nitrogen injection duration of 5 months is 197,3 thousand m^3; of 14 months – 0,038 m^3. According to the results from the statistical treatment of estimation data, the optimal value for the nitrogen injection duration was determined, which is 8,04 months. The ultimate gas recovery factor for the optimal period of the non-hydrocarbon gas injection is 58,11 %, and in the development of a productive reservoir for depletion – 34,6 %. Based on the research results, the technological efficiency of nitrogen injection into a productive reservoir has been determined at the boundary of initial gas-water contact in order to slow the movement of reservoir water into gas-saturated horizons. This study results allow the improvement of the existing technologies of hydrocarbon fields development under conditions of water drive. The use of the results of the research carried out in production will make it possible to reduce the volume of cumulative water production and increase the ultimate gas recovery factors to 23,51 %

Keywords: 3D field model, gas condensate reservoir, water drive, trapped gas, nitrogen injection

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1. Introduction

Most hydrocarbon fields in the final stage of development are characterized by the selective water flooding of productive layers and wells under conditions of low reservoir pressures.

Water flooding of productive layers during the manifestation of a water drive is a completely natural process, which, in turn, must be controlled [1]. To reduce the negative impact of the water drive on the process of reservoir development, it is necessary to control and regulate the movement of reservoir waters [2].

Natural gas fields in most cases are multi-layered and composed of rocks-collectors that are heterogeneous in permeability [3]. Partial water flooding of highly permeable layers causes a decrease in a well productivity due to the accumulation of a gas-liquid mixture at a bottom-hole [4]. Operations aimed to prevent the inflow of reservoir water to the wells often do not give positive results and are not effective enough. Given the impossibility of restoring the operation of production wells at the current horizon, they are forced to operate at reservoirs whose horizons are higher.

When water drive in the development of production reservoirs manifest themselves, wells are decommissioned after relatively small gas production due to the features in the industrial arrangement of gas condensate fields. For technological and economic reasons, the arrangement of gas condensate fields is not usually meant to collect and prepare gas with high water content.

Reservoir water is usually highly mineralized, causing corrosion of underground and ground equipment. Such complications are especially evident in the final stages of field development and require significant investments.

The issue of water flooding of productive reservoirs and gas condensate wells is extremely relevant at present for the world practice of hydrocarbon production. Given the above, there is a need for fundamental research and development of optimal ways to minimize the negative impact of reservoir waters on the process of development of gas and gas condensate fields. The new and improved hydrocarbon production technologies, based on the would-be research results, should ensure the highest ultimate hydrocarbon recovery factors at minimal cost with minimal burden on the environment.

2. Literature review and problem statement

The results reported in numerous studies [5], as well as the accumulated practical experience in the development of gas and gas condensate fields, indicate that when the water drive manifests itself during the development of productive reservoirs significant reserves of natural gas are trapped. According to the research results, the ultimate gas recovery factors under a water drive are 70–85 %.

Many technologies have been developed to enhance gas recovery from fields, the development of which is difficult due to the active inflow of reservoir water into gas-saturated formations, but most of them are ineffective or cannot be implemented from an economic point of view.

Based on the research results, the authors of [6] determined the high technological efficiency of secondary hydrocarbon production by injecting non-hydrocarbon gases into productive reservoirs (such as nitrogen, carbon dioxide, smoke and flue gases, as well as mixtures of various gases). However, the cited research did not study the issue related to the possibility of controlling the movement of reservoir water into gas condensate reservoirs using non-hydrocarbon gases.

The results from laboratory tests [7] show that the final coefficient of displacement of natural gas by various non-hydrocarbon gases depends on the type of displacement agent, the degree of heterogeneity of productive reservoirs, and the nature of interaction and mutual arrangement of heterogeneous interlayers [7]. However, up to now, the issue of selecting an injection agent, which would provide the highest technical-economic indicators, has not been investigated in detail; the conditions for them remain to be discussed.

Papers [8–10] report the results of laboratory tests to displace residual reserves of natural gas with nitrogen, carbon dioxide, and flue gases from the models of a homogeneous layer and heterogeneous two-reservoir models. During the research on the horizontal bulk models of the layer, the final coefficient of methane displacement with nitrogen, carbon dioxide, and flue gases varied within 73–87 % [8]. Results from the laboratory tests were implemented in the Budafa field (Hungary). As reported in [8], the use of flue gases is more profitable compared to carbon dioxide due to the relatively greater prevalence of flue gases and lower financial costs for the implementation of such a project.

Paper [9] reports the results of studying the displacement of methane with carbon dioxide and flue gases from homogeneous and heterogeneous two-reservoir models. The coefficient of methane displacement with carbon dioxide from the homogeneous models was 81 % at the time of reaching 2 % of its content in production gas. For the case of a heterogeneous model, the coefficient of methane displacement with carbon dioxide for a highly permeable layer was 77 %, and for a low-permeable layer – 10 %.

The results of the studies reported in works [8, 9] confirm the technological effectiveness of the introduction of secondary development technologies, which include the rational technologies of artificial active action on a productive reservoir using additional energy. However, the cited studies cannot fully characterize all physical processes occurring in the layer during nitrogen injection because they do not take into consideration the heterogeneity of productive reservoirs and the nature of the distribution of the geological environment.

According to the results reported in [10], it was found that the highest hydrocarbon recovery factor in the authors' experiments was achieved in the case of using carbon dioxide as an agent of injection. The final hydrocarbon recovery factor when methane is displaced by carbon dioxide was within 81–97,4 %. For the case of the use of flue gases and nitrogen as agents of injection to displace methane, slightly lower values of hydrocarbon recovery factor were achieved.

The reported findings are achieved due to the high displacing properties of carbon dioxide. The density and viscosity of carbon dioxide are much higher than the density of natural gas in reservoirs. Given the solubility of carbon dioxide in reservoir fluids (oil, condensate, reservoir water), a reduction in the viscosity of oil and condensate is provided, as well as the increased viscosity of water [11]. Injecting carbon dioxide into productive reservoirs ensures the increased mobility of hydrocarbon fluids and decreased water mobility [12].

It should be noted that the use of carbon dioxide leads to a series of issues, namely the corrosion of oil industry equipment and problems with the disposal of carbon dioxide, which must be resolved in the process of introducing this kind of technology.

Given the above, it is more rational to use nitrogen as an agent of injection. Nitrogen injection does not cause corrosion of well equipment and does not require the use of corrosion protection and high-quality corrosion-resistant materials [13]. Nitrogen is more accessible compared to carbon dioxide, it can be obtained from the air at relatively low costs using cryogenic, adsorption rigs, etc. [14].

The main drawback of the use of nitrogen as an agent of injection is the increased pressure at the onset of condensation of heavy hydrocarbons, which leads to a premature release of condensate in the layer [15].

The high efficiency of nitrogen application as an injection agent is evidenced by the results from laboratory tests. According to the results reported in [16], nitrogen injection into the water-encroached productive reservoirs makes it possible to increase the gas saturation of the porous environment and provide conditions for the movement of water-trapped natural gas.

Work [17] highlights the results of studying the process of nitrogen injection into water-encroached horizontal models, which confirm the technological effectiveness of its use to control the process of reservoir water movement. Due to the injection of nitrogen into the water-encroached zone of a reservoir, some of the trapped gas is pushed to the production wells. In the area of injection of non-hydrocarbon gas, reservoir pressure increases, and an additional hydrodynamic barrier is formed, which complicates the process of moving reservoir water into productive layers. However, it was not investigated over which period of the development of a gas condensate field it would be better to start nitrogen injection, in what quantity, and where exactly should the injection wells be located, at which distances.

Based on the results of numerous studies, it was established that the faster the technology of nitrogen injection is implemented in the field, the higher the efficiency of a given technology and the higher the ultimate hydrocarbon recovery factors [18].

The results of modeling the injection process of carbon dioxide [19] and nitrogen [20] into the reservoir indicate that the highest hydrocarbon recovery factor is ensured in the case of the development of a reservoir on depletion to the economically profitable limit, followed by the introduction of secondary technologies for the development of hydrocarbon reservoirs. The cited studies prove the effectiveness of the use of non-hydrocarbon gases in order to increase the ultimate hydrocarbon recovery factors but do not take into consideration the specific features of the final stage of development and the macro homogeneous structure of layers.

Analyzing the results of research [21], it was found that the injection of non-hydrocarbon gases provides for much higher technical and economic results of the development of productive reservoirs. The introduction of technologies of secondary hydrocarbon production allows for the greater reliability of productivity capabilities of the field.

Based on our analysis of the results from the laboratory and theoretical studies, it can be argued that in order to maximize the coverage of the productive reservoir it would be desirable to fully prevent the movement of reservoir water into productive reservoirs. The known methods to control the movement of reservoir water into productive reservoirs are usually economically disadvantageous and technologically unacceptable since the heterogeneity of rocks-collectors introduces significant uncertainty in the process of justifying certain technologies of increasing hydrocarbon recovery. Up to now, no practical solution to this issue has been found.

To improve existing technologies of the hydrocarbon reservoirs development, it is advisable to conduct additional research in order to improve hydrocarbon recovery. Based on the would-be results of our study, it is necessary to establish the type of a non-hydrocarbon agent and the conditions under which the highest ultimate hydrocarbon recovery factors could be reached.

3. The aim and objectives of the study

The aim of this study is to determine the impact exerted by the duration of nitrogen injection into a productive reservoir on the recovery factor of natural gas using numerical modeling. Applying the would-be results of our study could justify the optimal duration of injection of non-hydrocarbon gas, at which the highest technical and economic results in the development of gas and gas condensate fields are achieved when a water drive manifests itself.

To accomplish the aim, the following tasks have been set:

– to investigate the impact exerted by the different duration of nitrogen injection into a productive reservoir at the boundary of initial gas-water contact on the process of the movement of reservoir water;

– to establish the optimal duration and technological effectiveness of nitrogen injection into a productive reservoir at the boundary of initial gas-water contact for the conditions of a particular field.

4. Materials and methods to study nitrogen injection into a productive reservoir

The main tools of hydrodynamic modeling, Eclipse and Petrel by Schlumberger (USA), were used to investigate the peculiarities of the development of a productive reservoir when water drive manifests itself, and to devise optimal ways to improve hydrocarbon recovery.

In order to reliably reproduce the physical processes that occur in a productive reservoir in the process of nitrogen injection, a composite PVT model was applied [24]. The study is based on the example of a three-dimensional digital model of the gas condensate reservoir.

The conceptual digital three-dimensional model of a gas condensate reservoir is shown in Fig. 1.

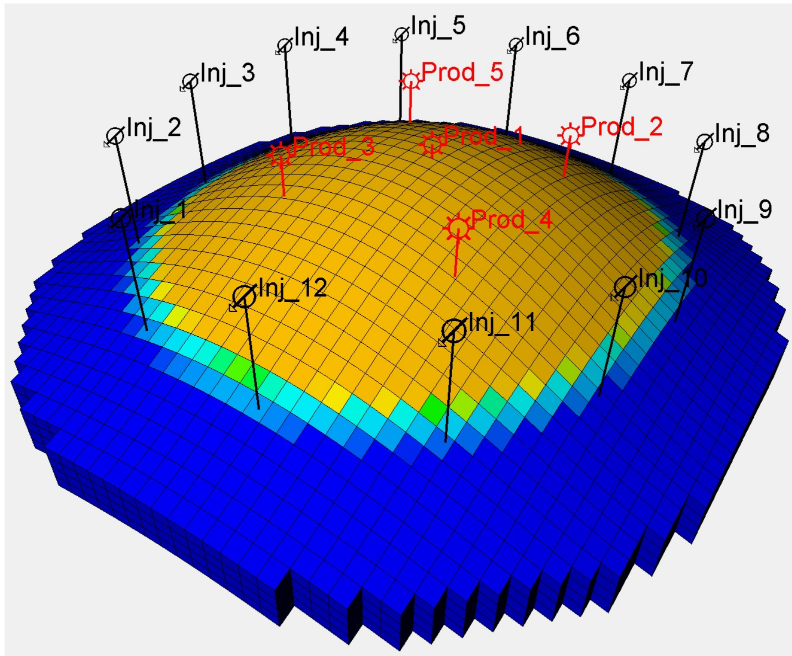

Fig. 1. Conceptual digital 3D model of a gas condensate reservoir

The main parameters of the digital model are the initial reservoir pressure, 35 MPa; reservoir temperature, 358 K; the effective porosity, 0,18; the coefficient of absolute permeability of the layer, $8.65 \cdot 10^{-3}$ μm^2; the initial gas-saturation coefficient, 0.8; the thickness of the layer, 15.4 m; the depth of the productive layer, 3,300 m. Gas reserves are 800.9 million m^3; condensate, 65.5 thousand tons.

A gas condensate reservoir is developed until depletion using 5 producing wells (Prod), which are operated under a constant gas flow rate drive. The gas flow rate of one well is 50 thousand m^3/day. Along the perimeter of the initial gas-water contact, there are 12 injection wells (Inj). Nitrogen injection is carried out at a rate of 50 thousand m^3/day per well. Our study was performed for the duration of nitrogen injection into the reservoir at the level of 5, 6, 8, 10, 12, 14 months.

Different duration of nitrogen injection into productive reservoirs predetermines different duration of production of productivity wells until its breakthrough. During our research, we registered, for different injection durations of non-hydrocarbon gas into productive reservoirs, the moment of nitrogen breakthrough into each productivity well. In the variant of developing a productive reservoir until depletion, the wells were stopped at the very moment in time similar to that in the development of the reservoir with the injection of nitrogen depending on the injection duration. Given the above, to establish the effectiveness of the examined technology, each variant of the reservoir development involving nitrogen injection corresponds to the option of developing a deposit until depletion depending on the injection duration.

Based on our study results, we calculated the main technological indicators for the development of a productive reservoir at the time of nitrogen breakthrough into one of the productivity wells by the largest amount of the produced reservoir water at the time of its breakthrough. The study results are represented in the form of graphical dependences of the examined parameters at the time of nitrogen breakthrough into one of the productivity wells depending on the injection duration.

Statistical analysis (intersection of tangents) [25] was used to treat the graphical dependences in order to determine the optimal points of the parameters studied.

According to the statistical analysis, the $f(x)=a_0+a_1x$ function values are selected so that the deviation of the studied points $(x_i; y_i)$ $i=\overline{1..N}$ from the selected curve is minimal. The parameters a_0, a_1 must be such that the sum of squares of the deviations of observed values y_i from those calculated for the $f(x)=a_0+a_1x$ function is minimal. After certain transforms, a system of two linear equations is received for the unknown regression parameters.

$$\begin{cases} \min\limits_{v,a_v}\left\{\sigma_{av}^2=\frac{1}{n_v-r_v}\sum\limits_{i=1}^{n_v}\left[f_v(a_v,x_i)-y_i\right]^2\right\}\Rightarrow\left\{\hat{v},\hat{a}_v\right\},\\ \min\limits_{\varepsilon,a_\varepsilon}\left\{\sigma_{a\varepsilon}^2=\frac{1}{n_\varepsilon-r_\varepsilon}\sum\limits_{i=1}^{n_\varepsilon}\left[f_\varepsilon(a_\varepsilon,x_i)-y_i\right]^2\right\}\Rightarrow\left\{\hat{\varepsilon},\hat{a}_\varepsilon\right\}.\end{cases} \quad (1)$$

$$f_v\left(\hat{a}_v,x_*\right)-f_\varepsilon\left(\hat{a}_\varepsilon,x_*\right)=0\Rightarrow x_*, \quad (2)$$

σ_{av}^2, $\sigma_{a\varepsilon}^2$ is the variance assessment of the f_v and f_ε effectiveness; r_v, r_ε is the number of the evaluated parameters of models $f_v(a_v,x)$ and $f_\varepsilon(a_\varepsilon,x_v)$.

The parameters a_0, a_1, a_2,..., a_n are determined by solving this system of equations. The parameters found are substituted in the equation $y=f(x)$: this technique produces linear equations that best describe the estimated data. After that, we build dependences for specific estimated data and approximate each of them by two straight lines, the point of intersection of which corresponds to the optimal value studied.

5. Results of studying nitrogen injection into a productive reservoir

5. 1. The impact of the duration of nitrogen injection into a field on the technical indicators of development

Based on the results of hydrodynamic calculations, it is found that the injection of nitrogen, at the boundary of a gas-water contact, helps maintain a reservoir pressure at the highest level compared to the depletion. Due to ensuring the reservoir pressure at the highest level, the stable well production is achieved under conditions of selective water fflooding.

The dynamics of reservoir pressure in the development of a reservoir until depletion and during the injection of nitrogen over 6 months are shown in Fig. 2.

The nature of the dependences of the dynamics of reservoir pressure over time is predetermined by the disconnection of productivity wells due to the breakthrough of nitrogen, or water flooding. In addition, the nature of changes in reservoir pressure is significantly affected by the activity of a water pressure system. The movement of reservoir water into productive reservoirs helps achieve a partial compensation for the production of hydrocarbons.

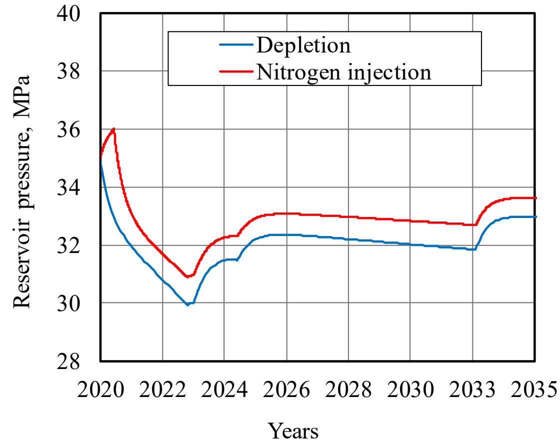

Fig. 2. Dynamics of reservoir pressure in the development of a reservoir until depletion and during the injection of nitrogen over 6 months

Based on the results of modeling the development of the productive reservoir, we conducted a comparative analysis of the dynamics of reservoir pressure depending on the duration of nitrogen injection. According to the results of our analysis, it was found that the nature of the dependence for almost all durations of nitrogen injection does not change, except for the injection duration of 5 months.

The resulting nature of the dependence is due to the introduction into productive reservoirs of large volumes of reservoir water and the decommissioning of some productivity wells because of the water flooding.

Based on the calculations, we analyzed the dependences of nitrogen breakout time into productivity wells depending on the injection duration. According to the results of the analysis, it was found that the increase in the duration of nitrogen injection leads to a decrease in the duration of the development of a productive reservoir until its breakthrough into production wells.

The dependence of the time of carbon dioxide breakthrough into production wells on the duration of its injection into a productive reservoir is shown in Fig. 3.

At the duration of nitrogen injection of 5 months, nitrogen breaks through to production wells after 42 months of operation; however, at the injection duration of 14 months, the time of nitrogen breakout is reduced to 30 months.

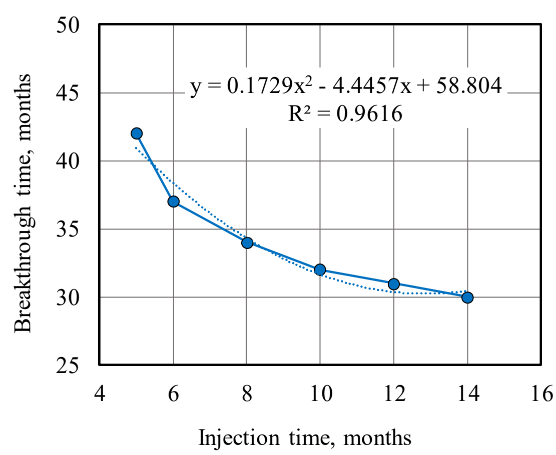

Fig. 3. Dependence of carbon dioxide breakout time into production wells on the duration of its injection into a productive reservoir

When analyzing the main technical indicators of the development of a productive reservoir, it is necessary to pay attention to the dynamics of reservoir water production and the nature of the water saturation of productive reservoirs during the injection of nitrogen. At the duration of nitrogen injection of 5 months, significant amounts of reservoir water are produced. The cumulative water production at the time of completion of the development of the reservoir is 197.3 thousand m^3. In the future, with an increase in the duration of nitrogen injection, water production is reduced. The cumulative water production at the time of completion of the development of the reservoir for the duration of nitrogen injection of 14 months is 0.038 m^3.

The cumulative hydrocarbon production and the forecast of gas recovery factor depending on the duration of nitrogen injection at the time of completion of the productive reservoir development are given in Table 1.

With the increase in the duration of nitrogen injection, the volumes of gas and condensate production are also reduced. The reason for this is a rapid breakthrough of nitrogen into production wells.

The state of the productive reservoir water saturation at the time of nitrogen breakthrough into the productivity well at the duration of nitrogen injection of 6 and 14 months is shown in Fig. 4.

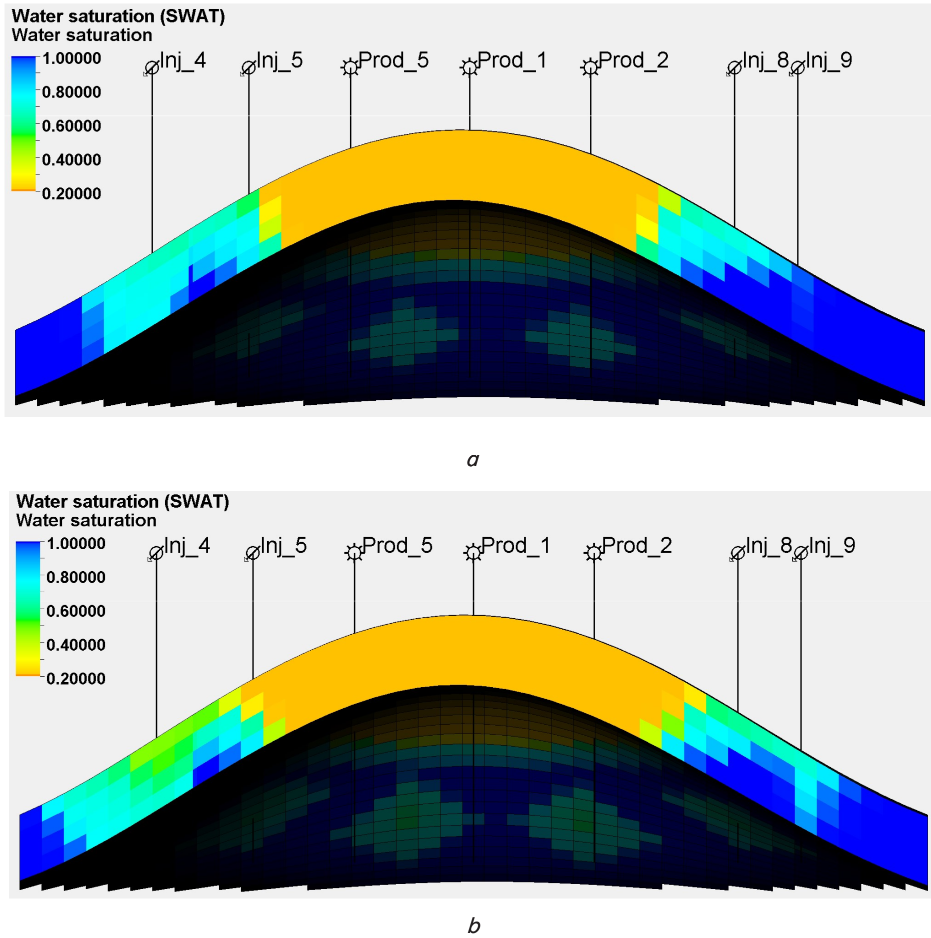

Fig. 4. The state of water saturation of the productive reservoir at the time of nitrogen breakthrough into one of the production wells at the duration of nitrogen injection: *a* — 6 months; *b* — 14 months

Table 1

The cumulative hydrocarbon production and the forecast of gas recovery factor depending on the duration of nitrogen injection at the time of completion of the productive reservoir development

Injection duration, month	Production cumulative			Gas recovery factor, %
	Gas, million m^3	Condensate, thousand m^3	Water, thousand m^3	
5	603.709	33.008	197,308.7	75.37
6	509.100	27.973	37.852	63.56
8	465.700	25.637	0.066	58.14
10	452.650	24.927	0.054	56.51
12	447.375	24.638	0.046	55.85
14	444.925	24.503	0.038	55.54

By analyzing the state of the productive reservoir water saturation, it was found that the injection of nitrogen at the initial gas-water contact has a positive effect on the process of natural gas recovery. With the increase in the injection duration, the gas-water contact rises more slowly compared to the development until depletion. The modeling results indicate the technological effectiveness of nitrogen injection at the initial gas-water contact in order to control the inflow of reservoir water into a productive reservoir.

5. 2. Determining the optimal duration of nitrogen injection into a productive reservoir

Based on the results acquired from modeling, we calculated the value of gas recovery factor at the time of nitrogen breakthrough into production wells by the volume of the cumulative production of reservoir water. By analyzing the results of our calculations, it was found that increasing the duration of nitrogen injection leads to a decrease in the coefficient of gas recovery factor.

The dependences of the gas recovery factor on the duration of nitrogen injection at the time of its breakthrough into one of the production wells and in the development of the reservoir until depletion are shown in Fig. 5.

The gas recovery factor depending on the duration of nitrogen injection is: 5 months – 39.86 %; 6 months – 35.27 %;

8 months – 32.09 %; 10 months – 30.63 %; 12 months – 29.53 %; 14 months – 28.65 %.

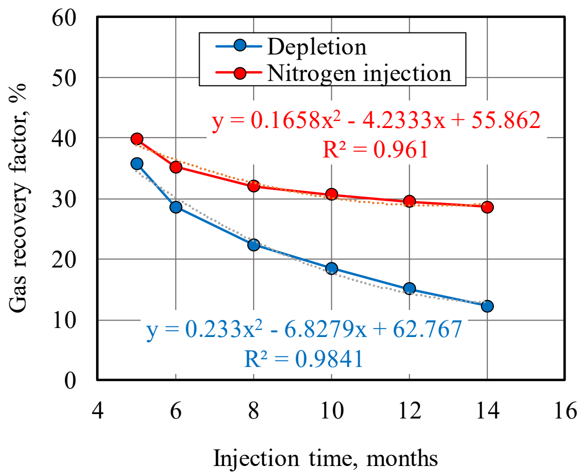

Fig. 5. Dependences of the coefficient of gas recovery factor on the duration of nitrogen injection at the time of its breakthrough into one of the production wells and in the development of the reservoir until depletion

In the development of a productive reservoir until depletion, the gas recovery factor depending on the duration of nitrogen injection is: 5 months – 35.82 %; 6 months – 28.62 %; 8 months – 22.39 %; 10 months – 18.49 %; 12 months – 15.15 %; 14 months – 12.27 %.

Based on the results of the statistical treatment of estimation data, we determined the optimal duration of nitrogen injection into a productive reservoir outside of which the gas recovery factor distribution does not change significantly. At the time of nitrogen breakthrough into one of the production wells, the optimal duration of injection is 8.04 months.

The ultimate gas recovery factor at the time of nitrogen breakthrough into the last production well when it is injected into a productive reservoir in order to slow the movement of reservoir water for the optimum duration of injection is 58.11 %. In the development of a productive reservoir until depletion, the ultimate gas recovery factor under these conditions is 34.6 %. Based on the results of the modeling of the development of a gas condensate reservoir, it was found that due to the introduction of the technology of nitrogen injection at the initial gas-water contact at the time of its breakthrough into production wells, the ultimate gas recovery factor is achieved that is 23.51 % higher compared to the depletion.

6. Discussion of results of studying the impact of the duration of nitrogen injection on the gas recovery factor

During the research, it was found that the increase in the duration of injection of non-hydrocarbon gas leads to a decrease in the duration of production well operation until its breakthrough into the wells (Fig. 3). Analyzing the results of the simulation, we can conclude that the phase permeability of nitrogen is much higher compared to the phase permeability for reservoir water. A significant differentiation of phase permeability provides much better conditions for the filtration of non-hydrocarbon gas in a porous space, which leads to a rapid breakthrough of nitrogen into production wells and causes them to stop. Production wells stop in order to ensure the conditioning of production gas with the basic requirements set by the Code of gas transmission system (nitrogen content, less than 5 %; the lower boundary of combustion heat, above 7,778 kcal/ m^3).

The increase in the duration of nitrogen injection leads to a decrease in the cumulative gas and condensate production (Table 1). By analyzing the results of our study, it is necessary to note the dynamics of production of reservoir water depending on the duration of nitrogen injection (Table 1). During the period of injection of 5 months, the cumulative water production at the time of completion of the development of a gas condensate reservoir is 197.3 thousand m^3. With an increase in the duration of the injection period to 14 months, there is a sharp reduction in water production; it is 0.038 m^3 (Table 1).

The modeling results are explained by the creation of an artificial barrier between water and natural gas, owing to the introduction of nitrogen injection technology. In addition, when injecting non-hydrocarbon gas, an additional hydrodynamic barrier is created at the interface of two phases. Based on our research, it was found that should the examined technology is implemented, a slowdown in the rise of a gas-water contact is achieved, which ensures the stable and waterless operation of production wells over a longer period of reservoir development.

Based on the results of the modeling, we calculated the forecast coefficients of gas recovery in the development of the reservoir until depletion and during nitrogen injection depending on the duration of its injection. Using the statistical analysis (intersection of tangents) to treat the results of the calculations, we determined the optimal value of the duration of nitrogen injection at the boundary of initial gas-water contact in order to slow the inflow of reservoir water into a productive reservoir. At the time of nitrogen breakthrough into production wells, the optimal injection duration is 8.04 months – (1), (2), Fig. 5.

With the introduction of the examined technology for the development of natural gas reservoir, a slowdown in the movement of reservoir water into the gas-saturated intervals of the reservoir is achieved. Thus, the process of trapping residual gas reserves with reservoir water is partially prevented; much higher ultimate hydrocarbon recovery factors are achieved. According to the results of our study, at the optimal duration of nitrogen injection, an increase in the gas recovery factor by 23.51 % is achieved compared to the development of a reservoir until depletion. The results of our studies show the technological effectiveness of nitrogen injection into productive reservoirs in order to increase the final gas recovery from productive reservoirs developed in the conditions of the manifestation of a water drive.

The study of the effectiveness of the use of secondary technologies for increasing hydrocarbon recovery under the conditions of active inflow of over-the contour waters into gas-saturated horizons was conducted on the basis of a homogeneous three-dimensional model of a gas condensate reservoir. When filtering hydrocarbons in a porous environment, a significant role belongs to the heterogeneity of productive horizons both in terms of area and thickness. Given the above, the dependences (Fig. 2–5) built according to the results of our research may be of a slightly different nature for the conditions of an actual reservoir. To confirm the effectiveness of the industrial implementation of nitrogen injection technology, it is advisable to conduct additional research using permanent geological and technological models of actual hydrocarbon reservoirs.

To implement the technology of nitrogen injection into productive reservoirs in order to prevent premature water flooding of productive reservoirs and production wells, it is necessary to provide stable sources of its evolution. The most common and cost-effective for the industry is the technique to receive nitrogen from the air. Until now, the technology of getting nitrogen from the air has been actively improved and is very reliable; however, it requires additional costs. The final decision on the expediency of implementing the technology of nitrogen injection into productive reservoirs should be made based on the results of a feasibility study.

Increasing of hydrocarbon recovery from depleted and water-saturated hydrocarbon reservoirs necessitates utilizing the results of this kind of research in order to improve producing development technologies in world practice.

7. Conclusions

1. We have established a significant impact of the duration of nitrogen injection at the boundary of initial gas-water contact on the main technical indicators of gas condensate reservoir development. The increase in the duration of nitrogen injection reduces the duration of reservoir development until its breakthrough into production wells. However, the introduction of the examined technology could decrease the volume of reservoir water production. At the duration of nitrogen injection of 5 months, the cumulative water production at the time of completion of the development of the reservoir is 197.3 thousand m^3; 14 months – 0.038 m^3. The modeling results allow us to argue that the introduction of nitrogen injection technology renders better control over the water inflow into productive reservoirs while better reliability of the field's recovery reserves is ensured.

2. The optimum duration of nitrogen injection into productive reservoirs has been established. The optimal injection duration at the time of its breakthrough into production wells is 8.04 months. The ultimate gas recovery factor when nitrogen is injected into a productive reservoir at the optimum injection duration is 58.11 %; in the development of the reservoir until depletion – 34.6 %. The results of our study show the technological effectiveness of nitrogen injection into productive reservoirs in order to slow the movement of reservoir water into gas-saturated horizons.

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