Technical science and innovation

Volume 2024 | Issue 3 Article 4

10-4-2024

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Recommended Citation
Shevtsov, Vladimir Mixaylovich; Igamberdieva, Lobar Zoirovna; and Zakirov, Azamjon Alimdjanovich (2024) "ESTABLISHING OPTIMAL PARAMETERS OF THE TECHNOLOGICAL MODE OPERATION OF A WATER-PENETRATING GAS WELL," *Technical science and innovation*: Vol. 2024: Iss. 3, Article 4.
DOI: https://doi.org/10.59048/2181-0400
E-ISSN: 2181-1180
.1609
Available at: https://btstu.researchcommons.org/journal/vol2024/iss3/4

UDC 622.276.013 (33.66)

ESTABLISHING OPTIMAL PARAMETERS OF THE TECHNOLOGICAL MODE OPERATION OF A WATER-PENETRATING GAS WELL

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Received: Jun 6, 2024; Accepted: Sep 30, 2024; Online: October 04, 2024;

Annotation. *The article discusses research on finding the optimal parameters of the technological operating mode of wells that minimize the water cut of well production, based on a detailed analysis of the geological and field characteristics of the deposit and materials from gas-hydrodynamic studies. Using the example of well 77 of the Sharkiy Berdak gas condensate field, the optimal parameters of the technological mode of its operation with minimal removal of formation water in its production were determined according to the data of gas-hydrodynamic studies. Analyzing the obtained results of processing data from gas-hydrodynamic studies, recommendations were made to install a 12 mm nozzle as the optimal operating mode with minimal removal of formation water.*

Key words: *multi-layer field, natural gas, technological regime, optimal parameters, well, residual reserves, gas and condensate recovery.*

Annotatsiya. *Maqolada uyumning kon-geologik xususiyatlarini va gaz-gidrodinamik tadqiqotlar materiallarini mufassal tahlil qilish asosida quduq qazib olishning suv kesishini minimallashtiruvchi quduqlarning texnologik ish rejimining optimal parametrlarini topish bo'yicha tadqiqotlar muhokama qilinadi. Sharqiy Berdaq gaz-kondensat koni 77-quduq misolida, gaz-gidrodinamik tadqiqotlar ma’lumotlariga ko‘ra, uni qazib olishda qatlam suvini minimal olib tashlash bilan ishlashning texnologik rejimining optimal parametrlari aniqlandi. Gaz-gidrodinamik tadqiqotlar ma'lumotlarini qayta ishlashdan olingan natijalarini tahlil qilib, qatlam suvini minimal olib tashlash bilan optimal ish rejimi sifatida 12 mm shtutserni o'rnatish bo'yicha tavsiyalar berildi.*

Kalit so'zlar: *ko'p qatlamli kon, tabiiy gaz, texnologik rejim, optimal parametrlar, quduq, qoldiq zahiralar, gaz va kondensat bera olish.*

Аннотация. *В статье рассмотрены исследования по нахождению оптимальных параметров технологического режима работы скважин, минимизирующих обводненность продукции скважин, базирующиеся на детальном анализе геолого-промысловых характеристик залежи и материалов газогидродинамических исследований. На примере скважины 77 газоконденсатного месторождения Шаркий Бердак определены оптимальные параметры технологического режима её работы с минимальным выносом пластовой воды в её продукции согласно данным выполненных газогидродинамических исследований. Анализируя полученные результаты обработки данных газогидродинамических исследований даны рекомендации установки 12 мм штуцера как оптимальный режим работы с минимальным выносом пластовой воды.*

Ключевые слова: *многопластовое месторождение, природный газ, технологический режим, оптимальные параметры, скважина, остаточные запасы, газо- и конденсатотдача.*

Introduction

In the context of prospects for a significant growth in natural gas reserves of the fields of the Ustyurt region, their complex geological structure, including several levels of gas content; high initial water saturation of the formation, which determines the presence of formation water in the produced gas in any mode of operation of wells from the very beginning of their operation, it is relevant to establish optimal parameters for the technological mode of operation of gas production wells with minimal fluid removal, ensuring an extension of their service life and, thereby, an increase final gas and condensate recovery from the field.

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Geological exploration works (GEW) require large time and financial expenditures to identify hydrocarbon (HC) deposits, therefore, increasing gas and condensate recovery of already discovered HC deposits is an important problem, the solution of which determines the saving of significant capital resources in the oil and gas production industry. Besides, drilling of new wells instead of those abandoned due to watering is often unprofitable economically. Therefore, finding solutions to extend the life of existing wells, along with increasing gas and condensate recovery of the field, will also save financial costs for additional drilling.

In the light of the above stated, the research on finding the optimal parameters of the technological mode of well operation, minimising the water cut of well products, based on a detailed analysis of geological and field characteristics of the deposit and materials of gas-hydrodynamic studies [1, 14].

The geological and field characteristics of the deposit include [2, 15]:

- the overall size of the gas-bearing reservoir, changes in the total and effective thickness of the reservoir over the area and section, the boundaries of the gas-bearing deposit, the size of screens and impermeable inclusions, the position of the gas-water contact (GWC) and its changes during development.
- reservoir and filtration properties of the reservoir: porosity, permeability, hydraulic conductivity, conductivity, compressibility of reservoir rocks, gas saturation, reservoir, bottom hole and wellhead thermobaric conditions, their variation over the area and section of the reservoir, as well as along the borehole of gas production wells.
- physical and chemical properties of reservoir fluids (viscosity, density, compressibility coefficient, gas moisture).
- hydrodynamic and thermobaric conditions in the wellbore.
- changes in phase states during gas movement in the reservoir, wellbore and surface gathering system.
- conditions on accumulation and removal of liquids and solid impurities from the bottomhole, efficiency of their separation.
- corrosion conditions, the degree and nature of their changes during GDR of wells whose products contain aggressive components.
- technological mode of well operation in the presence of complicating factors: destruction of the formation bottom-hole zone; presence of bottom water; thermobaric conditions of the productive formation; multilayer and heterogeneous reservoir properties; aggressive components in the composition of extracted products, design of underground and aboveground well equipment.

Methods and materials

Gas-hydrodynamic studies are subdivided into primary, current and special [2, 15]. Primary well testing of exploration and production wells. They are carried out in full and make it possible to determine formation parameters, its productive characteristic, establish the production potential of the well, as well as the relationship between flow rate, formation, bottom hole and wellhead pressures and temperature, well operation mode and the presence of liquid and solid particles in their products, initial formation pressure, the degree and quality of formation opening, etc.

Ongoing well testing is carried out during well operation in order to obtain the necessary information for analysing and controlling development. At the initial stage of development, well tests are carried out at least once a quarter, covering 25% of the existing well stock. After transition of the deposit to the main stage of development, evaluation of its reserves according to the operation data (dependence between gas withdrawal and the rate of reservoir pressure drop), the periodicity of well testing with reservoir pressure measurement is 1-2 times a year, not less than 50% of the well stock [3, 5, 9, 16].

Special studies are carried out to determine parameters determined by specific tasks in specially selected wells: determination of intervals of formation fluid inflow; control over the position of gas-water contact; study of the degree of corrosion of downhole equipment under different operating modes; determination of the degree of depletion of individual reservoirs during development and possible gas flow from one horizon to another when they are jointly opened by a single filter; study of the influence of carried out liquids and rock (bottom-hole destruction); study of the influence of the formation fluids and rocks on the development of the wells; study of the influence of the wells on the flow of gas from one horizon to another; study of the influence of the formation fluids and rocks on the development of the wells.

The following parameters are determined during the GDR process [2, 8, 9, 15]:

- static pressure at the wellhead and the reservoir pressure calculated on its basis.
- bottomhole pressure at different well operating modes and formation pressure as measured by a depth gauge.
- the process of pressure recovery and stabilisation is recorded by a self-recording manometer or at intervals by a reference manometer.
- well flow rate based on data from a washer or diaphragm critical flow meter (DCFM) installed at the wellhead or gauging station.
- quantitative and qualitative characterisation of fluid and solid impurities carried with well production.

- temperature downhole, along the borehole and at the wellhead.

Gas-hydrodynamic investigations and processing of their results are performed according to the instructions of the “Instruction” [4].

Gas-hydrodynamic studies of the well are carried out in five forward and one reverse modes of its operation. At the same time, pressure and temperature measurements are carried out, as a rule, with electronic manometers-thermometers.

When using a DCFM in well logging, a critical gas flow through the washer or diaphragm in this device is a prerequisite [4]. If this condition is met, well testing is carried out without gas release to the atmosphere, but into the plume. During well testing into the plume at the modes when critical flow is not observed, well logging data processing is performed taking into account the backpressure in the plume. In this case, the well flow rate is determined by pressure drop [2] using formula:

$$Q = 1700\,\alpha\,\varepsilon\,K_1 K_2 d^2 \sqrt{\frac{1}{\bar{\gamma}\,T\,Z}}\,\sqrt{PH_{\text{mc}}}, \quad (1)$$

where P – absolute pressure upstream of the diaphragm; H_{mc} – measured pressure drop in mm of mercury column; d – orifice diameter of the diaphragm, cm; Z – compressibility coefficient; T – gas temperature upstream of the diaphragm; $\bar{\gamma}$ – relative gas density; α – flow coefficient; ε – correction multiplier for jet expansion; K_1 – correction multiplier for orifice inlet edge unsharpness; K_2 – correction multiplier.

The flow coefficient α is determined depending on the orifice modulus $m = d^2/D^2$ according to the graph [1], the correction factor for the jet expansion ε is determined according to the graph [1] depending on the ratio $\frac{H_{\text{рт}}}{P_{\text{рт}}}$ and diaphragm modulus, where D is the pipeline diameter, cm.

Correction multiplier for the sharpness of the diaphragm inlet edge K_1 is determined in cases when the diaphragm orifice edge has a blunting (rounding) noticeable to the naked eye. Then, depending on the d/D ratio tabulated in [2], the value of K_1 is determined. At small gas flow rates and a large value of the d^2/D^2 ratio the coefficient α depends on the Reynolds number Re. In this case the coefficient α is multiplied by correction factor K_2 depending on the value of Re and the ratio d^2/D^2 [2].

The critical parameters (P_{cr} and T_{cr}) and relative gas density are calculated based on the component composition of the gas at GDI [1, 6, 7].

Results and discussion

On the basis of the performed research in [1, 11, 13] approaches to determining the optimal parameters of the technological mode of operation of gas production well minimising the presence of water in its products were developed. Let's consider on the example of well 77 of Sharkiy Berdak GCF determining the optimal parameters of the technological mode of its operation according to the above approaches.

Well data:

production string – 122 mm – 2,724 metres;

face – 2,698 metres;

artificial face – 2,698 metres;

perforation intervals – 2367-2360; 2354-2348 m (horizon J_2^{3a});

- 73 mm tubing – 2340 m.

When processing the results of gas-hydrodynamic studies of well 77 (Table 1), the following critical parameters and relative gas density were used: P_{cr} = 46.66 kgf/cm^2; T_{cr} = 203.89 K; $\bar{\rho}$ = 0.6410.

GDR of well 77 was carried out on three modes – on washers of 16, 14 and 12 mm diameter installed alternately in the DCFM.

According to the methodological guidelines of the “Instruction” [2] gas flow rate and liquid yield, including condensate and water, were determined, presented in Table 1. As follows from this table, specific content of water carried out by produced gas varies from 4.96 cm^3/m^3 at 16.0 mm washer diameter to its complete absence in the produced gas – at 12.0 mm washer diameter.

According to the instructions of the “Instruction” [4] we find the moisture content of formation and separation gas under conditions of GDR (Table 2).

Analysing the results of calculations presented in Tables 2, 3 we come to the conclusion that the lowest water removal (absence of water) by the production of well 77 is observed in the third mode of operation of well 77 – with 12 mm washer. From comparison of the moisture content value with this indicator of formation conditions (5.5 g/m^3) the water carried out by gas is most likely conditioned (relict). This conclusion is also confirmed by the results of chemical analysis of carried water composition presented in Table 3. It follows from this table that the concentration of chloride ions in the gas-borne water during the hydraulic fracturing of well 77 is 6162.4 – 4910.8 mg/l (modes 1, 2). Concentration of these ions in formation water of Sharkiy Berdakh GCF is 88000-115000 mg/l [2, 10, 12], which is an order of magnitude higher than the analysed water (Table 3). At the same time in [2] it is noted that the concentration of chloride ions in produced water higher than 2900 mg/l is an indicator of the beginning of formation water in gas production wells of Sharkiy Berdakh GCF. That is in the water carried out on modes 1, 2 there are already signs of formation water of chlorine-calcium type [3]. At mode 3 (washer diameter 12 mm), water removal is not noted, although this mode is characterised by gas velocity at the bottom hole 5.91 m/s (Table 2), which is higher than the limit – 5.0 m/s, causing complete removal of liquid from the bottom hole [4].

Analysing the above obtained results of processing of GDR data, we come to the conclusion that the optimal operating mode of well 77, when the formation water removal is minimal or completely absent, takes place when installing a 12 mm nozzle, causing a gas flow rate of 70.22 thousand m^3/day.

Table 1

GDR results of well 77 of the Sharkiy Berdakh gas condensate field

Washer diameter, mm	Head pressure, kgf/cm^2	Gas consumption, thousand m^3/day	Formation		Depression on the formation, kgf/cm^2	Downhole gas velocity, m/s	Separation conditions		Fluid output		Cont. C_{5+} in produced gas, g/m^3
			pressure, kgf/cm^2	temperature, °C			pressure, kgf/cm^2	temperature, °C	condensate, g/m^3	water, cm^3/m^3	
16,0	24,10	84,86	71,7	81,9	34,80	8,99	20	30	19,23	4,96	34,38
14,0	29,10	79,25	-	-	30,72	7,51	18	28	24,46	2,97	41,58
12,0	34,71	70,22	-	-	25,89	5,91	16	26	26,59		45,39

Note: the well was investigated after the well overhaul.

Table 2

Results of Gas Moisture Content Determination during GDR of well 77

Washer diameter, mm	Pressure, kgf/cm^2	Temperature, °C	Gas moisture content, g/m^3
In the formation	71,7	81,9	5,50
16,0	20,0	30,0	2,00
14,0	18,0	28,0	1,90
12,0	16,0	26,0	1,80

Table 3

Chemical composition of water (mg/litre) carried out with gas during hydraulic fracturing of well 77 of the Sharkiy Berdakh gas condensate field

Mode	$Na^+ + K^+$	Ca^{2+}	Mg^{2+}	Cl^-	HCO_3^-	CO_3^{2-}	SO_4^{2-}	Total mineralisation
I	890,1	1891,8	544,8	6162,4	134,2	0	91,3	9714,6
II	413,2	1396,8	666,4	4910,8	146,4	0	96,1	7639,7

Mode	CO_2	Fe^{2+}	Fe^{3+}	Specific gravity at 20 °C	pH	Water type by Sulin
I	2,2	0	4,7	1,006	7,9	Calcium chloride
II	2,2	0	5,6	1,004	8,1	Calcium chloride

Conclusion

The considered methodological approaches to the establishment of optimal parameters of technological modes of operation of gas producing wells are based on the system analysis of the results of well testing under stationary filtration modes in the presence of formation water in the produced gas in any mode of operation.

The considered methodological approaches allow to establish optimal parameters of the technological mode of operation of a water-penetrating gas well minimising formation water removal during the development of multilayer natural gas fields with complex geological structures.

Modern methods of gas-hydrodynamic well studies allow to reasonably establish optimal parameters of the technological mode of operation of water-permeable gas wells, minimising the removal of formation water from the reservoir, ensuring the extension of their service life and, thus, increasing the final gas and condensate yield of the field.

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UDC 622.22; 66.016.512

JUSTIFICATION OF THE EFFECTIVENESS OF SOFTWARE FOR THE DESIGN OF OPEN-PIT MINING

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Received: Jul 10, 2024; Accepted: Sep 9, 2024; Online: October 04, 2024.

Abstract: *The article notes that the economic feasibility of implementing a project based on deposits directly affects the economy of the country and the region, as well as the construction of new facilities, the use of the most balanced approaches and design solutions in a complex will allow*

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