Analysis of the effectiveness of ways to improve the performance in underground gas storage wells

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Abstract. The article provides an assessment of the effectiveness of various ways to improve the productivity of wells in underground gas storage facilities. We conducted comparisons of the performance of wells of increased diameter in the interval of the productive reservoir with wells in which hydraulic fracturing or horizontal ending was carried out.

Keywords: UGS well, filtration law, gas debit, depression on the reservoir, pressure gradient on the well wall, drainage zone of the well.

1. Introduction

Today, there are 27 underground gas storage facilities (UGS) in service with a fund of 2,705 wells and daily withdrawal of about 800 million m³ at the beginning of the season.

The general scheme for the development of the underground gas storage system in Russia until 2030 [2] provides for an increase in the daily productivity of UGS to 1 billion m³/day by expanding existing and building new UGS.

Construction and launching of underground gas storage facilities for stable operation is a complex, high-cost and time-consuming process, therefore, if there are no geological risks, an increase in the daily productivity of operating UGS facilities is possible in the following ways:

- increasing the number of new wells in operation
- carrying out geological and technical measures (GTM) on the existing well fund.

It should be noted that the cost of building new wells is almost 3 times higher than the cost of geological and technical measures to increase well productivity. Therefore, to solve the problem of increasing the daily productivity of UGS wells, the following technologies can be recommended:

- increase in the diameter of the wellbore in the interval of the productive formation
- construction of horizontal wells
- hydraulic fracturing.

Parameters for selection of candidate wells for events:

- characteristics of the productive formation
- properties of the bottomhole formation zone
- thermobaric conditions
- proximity of contact with bottom- and edge-water
- the condition of the well equipment
- technical base of the operating organization.
2. Mathematical modeling of ways to improve the productivity of UGS wells and their comparative characteristics

We will analyze the effectiveness of the application of the considered methods for the conditions of underground gas storage.

The theoretical foundations and practical solutions to the issue of increasing the borehole diameter are described in [3, 4, 5], the authors propose the derivation of several formulas that allow assessing the effect of an increased borehole diameter on changing the parameters of the well operation:

1. Degree of depression reduction on a formation

\[ \delta_{\Delta R} = \frac{\Delta P_f}{\Delta P_f} = \frac{\delta_a + \frac{\delta_b}{14BQ}}{1 + \frac{\delta_b}{\delta_a + \frac{\delta_b}{14BQ}}} \]  

(1)

where \( P_f \) is the formation pressure, \( P_f' \) is the formation pressure while maintaining the flow rate after increasing the borehole diameter, \( \delta_a \) and \( \delta_b \) are coefficients that take into account the geometry of the well bottom, \( A \) and \( B \) are filtration resistances coefficients, \( Q \) is the gas debit.

2. Degree of increase in well production rate:

\[ \delta_Q = \sqrt{1 + \frac{B \delta_b}{A^2 \delta_a} \Delta P_f^2} - 1 \]  

(2)

where \( \Delta P_f = P_f - P_{bot}^2 \); \( P_f \) is the formation pressure; \( P_{bot} \) is the bottomhole pressure.

3. Degree of decrease in pressure gradient on the borehole wall:

\[ \delta_{grad} = \frac{\delta_a + \frac{\delta_b}{14BQ}}{1 + \frac{\delta_b}{\delta_a + \frac{\delta_b}{14BQ}}} n \]  

(3)

where \( R_i \) is the radius of the well drainage zone, \( r_w \) is the radius of the well by the bit, \( n \) is the graduation of the change in the diameter of the well in the zone of the productive formation.

3. Results

Figure 1 shows the results of calculating the values of \( \delta_Q, \delta_{\Delta P}, \delta_{grad} \) with the multiplicity of increasing the well diameter \( n = 2, 3, 4 \) and different values of the fluid debit \( Q \).

Figure 1 shows that with an increase in the borehole diameter in the interval of the productive formation, the well flow rate increases, depression on the reservoir decreases, and the pressure gradient on the wellbore wall significantly decreases.
In the oil industry, many domestic and foreign studies are devoted to wells with horizontal completion: [5-12].

It should be noted that most of the works relate to oil horizontal wells under the assumptions: the reservoir is isotropic, filtration occurs according to Darcy's law, the flow density is unchanged throughout the entire length of the horizontal wellbore. The use of horizontal wells for the development of gas fields and for the operation of UGS facilities gave a powerful impetus to the development of the theory of gas inflow to a horizontal well, considering the specifics of their operation. To construct the field of velocities and pressures in the zone of formation drainage by a horizontal well, numerical methods of integrating the filtration equation in two and three dimensions are widely used. Ultimately, the dependence of the well flow rate on the depression on the reservoir is established.

At the same time, approximate formulas [6-12] proposed by several authors give quite acceptable results in comparison with numerical methods.

In [13], the inflow to the well after hydraulic fracturing is considered, which is the most effective way to increase the production rate of wells.

After hydraulic fracturing, the flow rate of the well, generally increases sharply. However, in underground gas storage, this method is used very rarely, which is associated with the cyclical operation of wells.

To compare the described methods of increasing the productivity of UGS wells, we will use the formulas for calculating the function of the geometrical dimensions of the reservoir drainage zone for the linear filtration law presented in [14].

The equation of gas inflow to the well with a nonlinear filtration law has the form [5]:

\[
\Delta P^2 = AQ + BQ^2, \quad (4)
\]

Filtration resistance coefficients A and B are determined based on the results of gas-dynamic studies. Analytically, these coefficients can be presented in the formulas:

\[
A = \frac{a}{k} f_a(r, h), \quad (5)
\]
\[
B = \frac{b}{\sqrt{k}} f_b(r, h), \quad (6)
\]

where \(a\) and \(b\) are the coefficients that consider the properties of gas, reservoir and thermodynamic conditions,

\[
a = \mu P_o T_f z_f, \quad (7)
\]
\[
b = \beta \cdot \frac{\rho_o P_o T_f z_f}{T_o}, \quad (8)
\]

where \(T_o, P_o\) are temperature and pressure under normal conditions, \(T_f\) is formation temperature, \(z_f\) is gas supercompressibility coefficient (average over the drainage zone), \(h\) is the thickness of the formation, \(\beta\) is the coefficient of vortex resistance; \(k\) is the permeability coefficient; \(\mu\) is the gas dynamic viscosity factor, \(\rho_o\) is gas density and \(f_a(r, h), f_b(r, h)\) are functions of the geometrical dimensions of the formation drainage zone by the well.

As a result of the transformations, we obtain the following formulas:

- for a vertical well enlarged in \(n\) times larger diameter

\[
f_a(r, h) = \frac{1}{nh} \ln \frac{R_s}{n \cdot r_c}, \quad (9)
\]

- for horizontal well

...
the drawdown \( f_a(\ell, h) = \frac{1}{\pi \ell h} \left( R_e^2 + \frac{2}{\pi} \sqrt{R_e^2 + \ell^2} \left( \frac{h}{2} \right)^2 + \frac{2}{\pi} \ln \frac{h}{2} + \frac{h}{2} \ln \frac{h}{2r_c} \right) \); \hspace{1cm} (10)

where \( \ell \) is a half-length of a horizontal well, \( h \) is the thickness of a productive layer;
- for a vertical fracking crack that penetrate the formation to its full thickness

\[ f_a(\ell, h) = \frac{1}{\pi \ell h} (\ln \frac{\pi R_e}{2\ell}). \hspace{1cm} (11) \]

where \( \ell \) is the half-length of the crack hydraulic fracture;

Table 1 reflects a comparative assessment of mechanical methods of impact on the bottomhole formation zone. In the calculations, it is assumed that the thickness of the formation is 10 m, the radius of the well is 0.15 m, and the radius of the well feed loop is 350 m.

Table 1. Comparative assessment of mechanical methods for increasing the productivity of wells of underground gas storage

| The degree of increase in the well diameter \( n \) | Well diameter with expanded well, m | Required length of hydraulic fractures crack, m | Required length of horizontal well, m |
|-----------------------------------------------|-----------------------------------|-----------------------------------------------|-------------------------------------|
| 2                                            | 0.4                               | 0.66                                          | 8.4                                 |
| 3                                            | 0.6                               | 0.98                                          | 9.6                                 |
| 4                                            | 0.8                               | 1.32                                          | 10.4                                |
| 5                                            | 1.0                               | 1.64                                          | 11.2                                |

Table 1 shows that the maximum increase in the wellbore diameter in the interval of perforation of the productive formation with modern technical means with a multiplicity of \( n = 5 \) can be compared with the length of the horizontal ending of about 11 m or the length of hydraulic fractures crack 1.64 m while maintaining the gas flow rate.

4. Conclusion

Expansion of the wellbore in the interval of the productive formation shows the greatest effect of increasing the productivity of high-production wells, while the depression on the reservoir remains minimal. With a well flow rate of more than 100 thousand m\(^3\)/day, for reliable well operation, it is better to set the technological regime according to the pressure gradient on the wellbore wall. If a well has a gas flow rate of less than 100 thousand m\(^3\)/day, then an increase in the well diameter does not lead to the expected increase in well productivity.

The operating well fund of UGS facilities with a low flow rate is about 37%, therefore it is necessary to consider other technologies to increase the productivity of wells. From an energy point of view, when comparing a hydraulic fracture of a formation comparable in length and a horizontal well, a hydraulic fracture will be more effective, but here it is necessary to consider the characteristics of the productive formation in each specific case, taking into account the specificity of the operation of UGS wells.

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