Evaluation of the results of exploitation of directional wells in underground gas storage

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Abstract. The article presents an assessment of the effective use of directional wells as a way to increase the productivity of underground gas storage. It analyzes the solutions to the problem of gas inflow to a horizontal well based on the use of a flat model of filtration flows. Evaluation of the efficiency of operation of directional (horizontal) wells was carried out using the example of the Kushchevsky underground gas storage.

Keywords: directional well, horizontal wellbore, horizontal well profile, absolute and relative well productivity, reservoir drainage zone of horizontal well.

1. Introduction
The technology of using horizontal wells can be considered as one of the perspective technical solutions for increasing the productivity of wells for underground gas storage (UGS), if there is a reliable justification for the effectiveness of opening a productive formation with a directional or horizontal wellbore. Drilling directional wells with horizontal wellbore from existing wells is significantly cheaper than building new wells. Besides, the trajectory of the directional wellbore passes near the old well, where the productive zone has already been characterized with core and geophysical data, as well as the results of gas-dynamic studies of reservoirs and a retrospective analysis of the technological modes of well operation.

2. Problem statement
At the initial stage of development, the technology of using horizontal wells was necessary only for reaching oil or gas deposits located under natural (lakes, rivers, etc.) and artificial (settlements, industrial structures, etc.) obstacles which are inaccessible for vertical wells [1, 2]. The basis for the design of horizontal wells is the choosing of the optimal profile, which depends on the field development system adopted at the enterprise, as well as the geological and technical conditions for drilling.

The high productivity of horizontal wells allows, at the same flow rates, to significantly reduce the drawdown in the bottomhole zone at the same flow rates, which also reduces the coning of the bottom water and the destruction of the reservoir formation. The turbulence of the flow near the bottomhole is significantly reduced during the gas flow.

Nowadays the technology of using horizontal wells clearly the problem of maintaining and increasing well productivity, but at the same time has several significant disadvantages [3]:

– horizontal well construction cost by 10 - 50% (depending on the length of the horizontal section) is greater than a vertical well.

– the possibility of formation of water seal because of the wrong choice of the profile of the horizontal wellbore;
significant influence of the anisotropy parameter during the opening of productive heterogeneous formations with a horizontal wellbore;
- technical and technological difficulties associated with the development, research and repair and maintenance work in horizontal wells.

The first experimental drilling of horizontal wells for underground gas storage facilities was started at the Kushchevskoye UGS facility. This UGS facility has become a testing ground for assessing the efficiency of horizontal wells in heterogeneous reservoirs, since in geological terms, a natural reservoir is an alternation of low and high permeability sandy-siltstone layers.

3. Evaluation of the effectiveness of using horizontal wells technology in underground gas storage

The productivity of directional gas wells can be determined numerically for any configuration of the drainage zone of the horizontal wellbore. In the general setting, the problem of gas inflow to a horizontal well is three-dimensional and has no analytical solution. Therefore, numerical methods for solving this problem are now widely used, or approximate solutions based on analytical models are being used to reduce a three-dimensional problem to a two-dimensional one. At the same time, approximate formulas proposed by several authors give quite acceptable results in comparison with numerical methods. In the literature, many solutions to the problem of gas inflow to a horizontal well are based on the use of a flat model of filtration flows. As can be seen from above, there is sufficient certainty in calculating the function of the geometric dimensions of the drainage zone of the formation by the well \( f_a(\ell, h) \). Comparison of the calculated values of the functions \( f_a(\ell, h) \) according to the formulas of a number of authors \([4, 5, 6]\) when \( h = 10 \) m, \( r_c = 0,15 \) m, \( R_c = 350 \) m, is shown in the Figure 1.

![Figure 1](image)

**Figure 1.** Comparison of the calculated values of the functions \( f_a(\ell, h) \)

According to the Figure 1 the function \( f_a(\ell, h) \) has values of the same order, which indicates the convergence of various formulas.

In work \([7]\), based on real data from gas-dynamic studies of low-debit and high-rate wells of the existing UGS facility, possible filtration resistance coefficients and flow rates for design directional wells of different profiles were calculated, taking into account the penetrated thickness of the formation taken as 100 m (Table 1).

To assess the effectiveness of the proposed measures, it is necessary to calculate the gas flow rate at the maximum possible depression on the reservoir of 0.4 MPa, what was decided based on the results
of gas-dynamic studies for the terrigenous reservoir. The minimum boundary condition for the operation of the well is the flow rate, at which the optimal pressure is maintained, which is necessary for the gas movement along the wellbore, the loop and the field gas-collecting manifold to the booster compressor station. The largest value of the maximum flow rate is limited by the pressure at the inlet of the booster compressor station. The analysis shows that at the beginning of production, high-rate wells, as a rule, have a large potential for production, which has to be limited, while the productivity of low-debit wells is at the border of the minimum conditions for normal operation. At the end of the withdrawal period, only high-rate wells remain in operation, which by this time become average-rate wells, which significantly affects the maximum daily productivity of the entire UGS facility.

Table 1 - Initial operating parameters of real production wells of UGS facilities and recalculated taking into account the penetrated thickness of the reservoir for directional wells

| №   | Well characteristics         | Filtration resistance coefficients | Maximal gas flow rate, thousand m³/day |
|-----|------------------------------|-----------------------------------|---------------------------------------|
|     |                              | A, *10⁻⁴ MPa²/(thousand m³/day) | B, *10⁻⁴ MPa²/(thousand m³/day)²       |                                        |
| 1   | Unproductive                 | 34,43                             | 0,21                                  | 316,6                                 |
| 2   | Highly productive            | 8,54                              | 0,01                                  | 1050,3                                |
| 3   | Designed directional well №1 | 9,47                              | 0,02                                  | 971,3                                 |
| 4   | Designed directional well №2 | 4,92                              | 0,01                                  | 1795,7                                |

The results of calculating the gas flow rate for the sampling period with the maximum allowable drawdown in the reservoir ΔP = 0.4 MPa are presented in Table 2.

Table 2 - The results of calculating the gas flow rate for the sampling period for the analyzed wells

| №   | Well characteristics         | Gas flow rate, thousand m³/day | Reservoir pressure at the end of the gas withdrawal period, MPa |
|-----|------------------------------|--------------------------------|---------------------------------------------------------------|
|     |                              | in the beginning of gas sampling period | at the end of gas sampling period |                                        |
| 1   | Unproductive                 | 316,6                          | 277,5                                       | 3,16                                   |
| 2   | Highly productive            | 1050,3                         | 1036,3                                      | 3,85                                   |
| 3   | Designed directional well №1 | 971,3                          | 883,4                                       | 3,54                                   |
| 4   | Designed directional well №2 | 1795,7                         | 1575,3                                      | 3,42                                   |

Figure 2 presents the dynamics of the gas flow rate of a low-debit well and the corresponding directional well No. 1, high-rate and designed directional well No. 2.

The figure shows that the productivity of the designed directional wells significantly exceeds the productivity of real vertical wells. At the same time, the designed directional well No. 1 in productivity seems to be highly productive well, and the flow rate of directional well No. 2 throughout the sampling period is almost twice the productivity of the investigated vertical well.

Evaluation of the operational efficiency of real directional (horizontal) wells will be carried out using the example of the Kushchevsky underground gas storage. Проведя анализ профилей горизонтальных скважин Кущевского ПХГ, можно сделать следующие выводы:

- in many wells, about 30 meters of the perforated space is occupied by an insulating cement bridge, which was installed due to the fact that the horizontal wellbore extends beyond the productive formation;
- in most wells, the point of the deepest horizontal wellbore is located approximately in the middle of the filter, which can be the reason for the formation of water seal when pulling up the bottom and condensation water.
In order to assess the efficiency of operation of directional wells at the Kushchevskoye UGS facility and to determine whether the actual performance indicators of their work correspond to the design ones, an analysis of the results of gas dynamic studies was carried out.

Figure 2. Dynamics of gas flow rate of real UGS wells and designed directional wells

In order to assess the efficiency of operation of directional wells at the Kushchevskoye UGS facility and to determine whether the actual performance indicators of their work correspond to the design ones, an analysis of the results of gas dynamic studies was carried out.

Analysis of the data showed that for the Kushchevskoye UGS facility, the absolute productivity of horizontal wells is 1.5 times higher than for vertical wells, on average. For pads, this indicator varies from 1 to 4. However, if we consider the relative productivity per 1 m of filter length (perforation interval), this indicator is much higher for vertical well (average values for vertical wells are about 2.0 thousand m$^3$/day, for directional wells - 0.5 thousand m$^3$/day).

If we assume that the supply circuit of the entire pad is equivalent to the drainage zone of one vertical well, then according to the calculation, the optimal filter length in each horizontal directional wellbore was on average about 100 m. Almost half of the values of this indicator are covered by an interval of 90-120 m, and the maximum corresponds to about 200 m.

4. Conclusions
Evaluation of the effectiveness of the introduction of directional wells in a real underground gas storage shows a significant increase in the productivity of reconstructed wells with the existing surface facilities of UGS facilities.

The analysis of the operation of horizontal wells at the Kushchevskoye UGS facility indicates that:
- the actual performance of the wells is lower than the designed ones;
- the profiles of many directional wells do have not an optimal trajectory;
- the absolute productivity of directional wells is much higher than vertical wells;
- the relative productivity of directional wells is 4 times lower than that of vertical wells;
low productivity of directional wells is primarily associated with the long length and features of profile of the horizontal wellbore.

At the same time, it should be noted that at operating UGS facilities, the introduction of directional wells in undrilled sections of storage facilities will improve the gas injection scheme, reduce the distribution of gas to inactive peripheral zones, connect the top of the reservoir, and increase the drained gas-saturated pore volume of the storage facility.

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