Optimization of the Gas Wells Performance Indicators

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Abstract

The present article covers the issues of the gas wells production enhancement in view of appliance of the practice of well diameter enlargement within the interval of the productive formation. The main practices of enhancement of the gas wells production capacity and criteria of their efficiency are analyzed in brief. The review of Russian and global experience of appliance of the methods of optimization of the gas wells and fields performance indicators is made. The main effects of the practice of gas well bore enlargement in productive formation region are described. The formulae describing the level of change of the well production, drawn-down pressure and pressure gradient at the factor of well radius enlargement are given.

Keywords: field, well, gas well production, enlargement of well diameter, acid reamer.
Important role for solving of the tasks related to provision of optimal well production rates at high gas-recovery factors of the productive formation is assigned to the bottom-hole formation area recovery methods. The range of applied recovery practices and methods for the present area is quite wide. Reasonability of the performed actions shall be determined not only by achievement of the definite technological parameters of the gas fields development but also by the economic components which is very important in the present-day market environment of the low prices for the crude hydrocarbons.

The main engineering and technological directions of optimization of the gas wells performance can be distinguished for development of the domestic gas fields:

- enlargement of diameter of the existing wells;
- drilling of the side bores from the existing wells;
- hydraulic fracturing of formation and other methods of the formation bottom-hole area recovery;
- rod friction reduction in the flow string tubing and well-head assembly (enlargement of the tubing diameter and holes in the X-mas tree).

Analysis of the industrial materials and review of the technical literature determine the following directions of the formation bottom-hole area recovery:

- chemical bottom-hole treatment. Chemical bottom-hole treatment is applied quite often but the effect of such recovery is not always satisfying[1, 18; 2, 201; 3, 440; 4, 13; 5, 311; 6, 604];
- cleaning of the colmataged formation area with the well bore enlargement by hydraulic, chemical or mechanical methods [7, 62; 8, 400-404; 9, 84-87; 10, 25-28; 11, 140; 12, 31-34];
- exceedance of the colmataged formation area limits by means of drilling of the horizontal side bores, hydraulic fracturing of formation [13, 180; 14, 300; 15, 110; 16, 2; 17, 144; 18, 389; 19, 95-100].

The works of foreign authors also consider different directions of the bottom-hole area recovery in gas wells, including horizontal wells [20, 15-17; 21, 77-82; 22, 6]. Innovative technological practices for preservation of the bottom-hole area of formation in cavity wells of enlarged diameter, in wells with side horizontal bores and in wells with hydraulic fracture crack [23, 32] are being deeply studied at the present time by Gazprom UGS, LLC. Let us consider the criteria which help to evaluate one or other practice of the gas well production enhancement:

- maintenance of such draw-down pressure on the formation which will impede early water breakthrough;
- reduction of the formation draw-down pressure for the purposes of sustainable use of the formation energy[23, 34];
- enhancement of the well production with maintenance at the well wall of pressure gradient which determines reservoir failure and carrying over of rock (sand) from the formation into the well[23, 34].
Therefore the main purpose of these technological practices is maintenance of the critical pressure gradients preventing sand ingress upon condition of multiplying of the gas wells.

Drilling of large-diameter wells for production enhancement is one of the directions of scientific and technological progress in gas industry. For example, for wells with assumed production of more than 500 ths. m$^3$/day, large diameter of the casing string allows to use tubing from 100.3 mm in diameter, as a result, pressure losses resulting from friction and gas moving from the bottom-hole to the well-head decrease. Nevertheless, drilling of large-diameter wells requires substantial capital investments. Due to this fact it seems preferable to work with stock of already drilled marginal wells. It will be sufficient to enlarge the well bore within the interval of productive formation or to create cavern in the bottom-hole area. This can be implemented at the well completion stage after drilling or in the process of capital repair in the formations of different lithological composition and filtration channels structure.

B.B. Lapuk and V.N. Shchelkatchev have considered the theoretical basis of evaluation of efficiency of the well bore diameter enlargement [24, 609]. In the present works they have developed the formulae of well production under different conditions of stabilized liquid and gas inflow, they have confirmed the influence of the well radius on its production capacity which can be determined based on the type of inflow to the wells. Well radius $r_c$ is set as equal to the well bore radius by drill bit or by reamer. These authors have made the conclusion that expansion of radius by $n$-times has stronger effect on the drill bit than radius reduction by the same number of times. Practical decisions of the considered issue are described by Yu. P. Korotaev through the example of development of the Vuktyl gas-condensate field [25, 11-15].

The present article considers enhancement of productivity of the average well depending on the gas flow coefficients and production string nominal diameter of 140 mm, 146 mm and 168 mm. Among the works of the last decade special attention shall be paid to the articles of V.A. Vasiliev and coauthors, containing general views on the achieved results of the well diameter enlargement, analysis of well production changing, draw-down pressure on the formation and pressure gradient at the well wall, as well as energy-saving production for the well diameter enlargement [23, 35; 26, 108-113; 27, 65-75].

Several authors such as V.A. Vasiliev, T.A. Gunkina, V.A. Lushpeev note that efficiency of enlargement of the gas well bore diameter is much higher than enlargement of the oil ones. It can be explained by occurrence of non-linear filtration resistance.

Evaluation of wells having enlarged diameter can be made on the basis of energy-saving criterion:

- level of change of the energy-saving production $\delta_{QE} = \frac{\delta_2}{\delta_b}$;
- level of change of the formation draw-down pressure $\delta_{QFE} = \frac{\delta_2}{\delta_b}$,

where $-\delta_a$ and $\delta_b$ are the coefficients considering dimensions of the well bore-hole.

Due to this fact we can assume that under the definite mining and geological...
conditions the vertical wells with the bore enlarged within the interval of reservoir are commensurable to other innovative technological practices (drilling of side horizontal bores, hydraulic fracturing of formation, etc.) in view of productivity [23, 40].

In this work we investigate enlargement of the gas well diameter in the area of productive formation as the method of its production enhancement. All the applied methods of recovery of formation and bottom-hole area are aimed at enhancement of production at reasonable performance indicators of formation and well. Well production enhancement can be achieved with a help of the following main activities:
- increase of permeability;
- reduction of fluid viscosity;
- increase of formation pressure;
- reduction of bottom-hole pressure;
- control of external boundary radius and well radius.

The first four methods are studied sufficiently and are widely used all over the world. If we consider well diameter enlargement within the interval of productive formation at the stage of its construction it will be, as we have mentioned above, one of the quite capital-intensive methods of production enhancement. Enhancement of production of the operating well by means of enlargement of the bottom-hole area is a little cheaper and does not require substantial capital costs. The costs of hydraulic fracturing of formation, which is also widely applied as the method of well production enhancement, are much higher and cannot be compared to the costs of the previous methods.

The practice of well bore diameter enlargement within the interval of productive formation by means of dissolution of the carbonate components of rock by acid is described in the works of B.M. Sutchkov for conditions of the Udmurtia fields [5, 33]. It is recommended to apply this practice when carbonate content of rock exceeds 20%. Production enhancement occurs not only due to the well diameter enlargement but also due to dissolution and outflow of sludge from the most low-permeability contaminated formation area directly adjacent to the production string. Use of the acid solutions has allowed to enlarge well bore diameter in Udmurtia to 25-35 cm (when drill bit diameter amounts 216 mm), in Tataria – at the same diameter – to 53 cm.

The main disadvantage of the activities on the well diameter enlargement within the interval of productive formation is a limitation of the scope of application – it is possible only in the open-hole wells. Nevertheless geological conditions of the several oil and gas fields allow applying the practice of gas well diameter enlargement (Tchayandin, Orenburg, Medvezhie, some horizons of the Bovanenko oil and gas-condensate field).

As an example let us consider the results of industrial testing at several oil fields of Udmurtia (Mishkinskoe, Listvenskoe, etc.). In such a way after enlargement of diameter in the wells No. 2063, 1327, 1355, 714 of the Mishkinskoe field enhancement of production by 4.9; 4.4; 2.9 and 4.0 times respectively was observed. At the wells of Listvenskoe field No. 350 and 316 enhancement of the wells production by 16.6 and 3.6 times respectively was observed.
The modern reamers help both to make unlimited number of enlargement intervals in the well being drilled and to perform effective cleaning and enlargement of the bore well diameter down the hole with a help of fitted-in flushing nozzle and flow-conducting channels. Moreover acid-based reamers allow combining the effects of well diameter enlargement with acid treatment of the bottom-hole area of the productive formation.

The main effects from the well bore enlargement in the area of productive formation are given in the figure 1.

**Figure 1:** The main effects of the well diameter enlargement within the interval of the productive formation

Let us consider change of production, formation draw-down pressure and pressure gradient at the gas well wall.

The equation of the gas inflow to the well has the following form:

\[ \Delta P^2 = AQ_o + BQ_o^2, \]  

(1)

Where \( \Delta P^2 = P_{for}^2 - P_{bhp}^2 \); \( P_{for} \) – formation pressure; \( P_{bhp} \) – bottom-hole pressure; \( Q_o \) – gas rate under normal conditions; \( A, B \) – gas flow coefficients:

\[ A = a \cdot \ln \frac{R_K}{r_w}, B = b \left( \frac{1}{r_w} - \frac{1}{R_K} \right), \]  

(2)

where \( a \) and \( b \) – are the coefficients depending on the formation thickness, physical properties of liquid (gas) and filtration properties of the formation; \( R_c \) – radius of the formation drainage area of the gas well; \( r_w \) – well radius.
Well diameter enlargement by $n$ times will change the gas flow coefficients to the following values:

$$A' = \delta_a A B' = \delta_b B.$$  \hfill (3)

Where $\delta_a$ and $\delta_b$—are the coefficients considering geometrical dimensions of the well bottom-hole:

$$\delta_a = 1 - \frac{\ln n}{\ln \frac{R}{r_w}},$$ \hfill (4)

$$\delta_b = \frac{1}{n}.$$ \hfill (5)

Gas inflow equation under condition of the maintenance if gas rate to the well of enlarged diameter has the following form:

$$(\Delta P^2)' = A Q_o \delta_a + B Q_o^2 \delta_b$$ \hfill (6)

Equation of the formation draw-down pressure can be represented in the following form:

$$\Delta P = P_{for} - \sqrt{P_{for}^2 - \Delta P^2};$$ \hfill (7)

$$\Delta P' = P_{for} - \sqrt{P_{for}^2 - (\Delta P^2)'};$$ \hfill (8)

The formulae 6, 7 and 8 help to evaluate the level of reduction of the draw-down pressure on the gas formation upon condition of the rate maintenance:

$$\delta_{\Delta P} = \frac{\Delta P}{\Delta P} = \frac{\delta_a + \frac{\delta_b}{A^2} Q_o \delta_0}{1 + \frac{\delta_a}{A^2} Q_o}$$ \hfill (9)

Let’s write down the formulae for calculation of the well production upon condition of maintenance of the draw-down pressure:

$$Q_o = \frac{A}{2B} \left( \sqrt{1 + 4 \frac{B}{A^2} \Delta P^2} - 1 \right)$$ \hfill (10)

$$Q_o' = \frac{A \cdot \delta_a}{2B \cdot \delta_b} \left( \sqrt{1 + 4 \frac{B}{A^2} \delta_b \Delta P^2 - 1} \right).$$ \hfill (11)

Consequently, we obtain the level of the well production enhancement:

$$\delta_Q = \frac{Q_o'}{Q_o} = \frac{\delta_a}{\delta_b} \cdot \frac{\sqrt{1 + 4 \frac{B}{A^2} \delta_b \Delta P^2 - 1}}{\sqrt{1 + 4 \frac{B}{A^2} \Delta P^2 - 1}}$$ \hfill (12)
The pressure gradient for gas filtration is determined by the formula:

\[
\frac{dP}{dr} = \frac{\mu \cdot V}{K} + \beta \frac{\rho_g \cdot V^2}{\sqrt{k}},
\]

(13)

where \(\mu\) – gas dynamic viscosity coefficient under the formation conditions; \(V\) – velocity of gas filtering; \(k\) – permeability coefficient; \(\beta\) – eddy-making resistance coefficient; \(\rho_g\) – gas density under the formation conditions.

Taking into consideration the fact that the maximum value of the draw-down pressure is observed at the well wall, gas filtering velocity will be equal:

\[
V = \frac{Q_o \cdot P_o}{2\pi \cdot r_w \cdot h \cdot P_{bhp}},
\]

(14)

Where \(P_o\) – normal pressure; \(h\) – formation thickness.

So the equation 13 will have the following form:

\[
\left. \frac{dP}{dr} \right|_{r=r_w} = \frac{\mu P_o Q_o}{2\pi K h P_{for}} + \beta \frac{\rho_g P_o Q_o^2}{4\pi^2 \sqrt{K h^2 P_{for}} r_w^2},
\]

(15)

Decrease of the pressure gradient at the well diameter enlargement by \(n\) times is determined by the formulae 16, 17, 18 and 19:

\[
\left. \frac{dP}{dr} \right|_{r=r_w} = \frac{\mu P_o Q_o}{2\pi K h P_{for}} \frac{1}{n-r_w} + \beta \frac{\rho_g P_o Q_o^2}{4\pi^2 \sqrt{K h^2 P_{for}} r_w^2 n^2},
\]

(16)

or

\[
\left. \frac{dP}{dr} \right|_{r=r_w} = \frac{1}{2P_{for} r_w} \left( \frac{A}{n \ln \frac{R_k}{r_w}} Q_o + \frac{B Q_o^2}{r_w n^2} \right)
\]

(17)

The level of decrease of the pressure gradient is determined by the formula:

\[
\delta_{grad} = \left( \frac{dP/dr}{dP/dr} \right)'
\]

(18)

or

\[
\delta_{grad} = \frac{\delta_a + B \ln \frac{R_k}{r_w} Q_o \delta_b}{1 + \frac{B}{A} \ln \frac{R_k}{r_w} Q_o} \cdot n
\]

(19)
The results of calculation of the values \( \delta Q \), \( \delta \Delta P \) and \( \delta \text{grad} \) at the well diameter enlargement ratio \((n = 2 \text{ и } 3)\) and different values of the gas rate \( Q_o \) for typical gas well are given in the Table 1 \((R_c = 250 \text{ м}, A = 0,01 \frac{MPa^2}{ths.m^3/ day}, B = 9,5 \cdot 10^{-5}\))

\[
\frac{MPa^2}{(ths.m^3/ day)^2}, P_{in} = 10 MPa
\]

**Table 1:** Level of change of the well production \( \delta Q \), formation draw-down pressure \( \delta \Delta P \) and pressure gradient \( \delta \text{grad} \) at the well radius enlargement by \( n \) times

| \( n \) | \( Q_o=50 \)  
| ths. m\(^3\)/day. | \( r_c=0,057 \) m | \( Q_o=100 \)  
| ths. m\(^3\)/day. | \( r_c=0,057 \) m | \( Q_o=250 \)  
| ths. m\(^3\)/day. | \( r_c=0,073 \) m | \( Q_o=1000 \)  
| ths. m\(^3\)/day. | \( r_c=0,109 \) m |
| --- | --- | --- | --- | --- | --- | --- | --- |
| \( \delta \Delta P \) \( \delta Q \) \( \delta \text{grad} \) | \( \delta \Delta P \) \( \delta Q \) \( \delta \text{grad} \) | \( \delta \Delta P \) \( \delta Q \) \( \delta \text{grad} \) | \( \delta \Delta P \) \( \delta Q \) \( \delta \text{grad} \) |
| 2  | 0,77  | 1,22  | 0,29  | 0,71  | 1,28  | 0,27  | 0,62  | 1,34  | 0,26  | 0,53  | 1,39  | 0,25  |
| 8  | 8      | 4      | 0      | 3      | 5      | 1      | 1      | 7      | 1      | 8      | 5      | 3      |
| 3  | 0,68  | 1,38  | 0,14  | 0,59  | 1,48  | 0,13  | 0,48  | 1,59  | 0,12  | 0,38  | 1,69  | 0,11  |
| 3  | 4      | 9      | 0      | 8      | 0      | 3      | 5      | 9      | 1      | 1      | 5      | 4      |

According to our calculations, production increases, formation draw-down pressure decreases, pressure gradient at the well wall significantly decreases as far as well bore diameter enlarges.

Decrease of the draw-down pressure on the gas formation allows not only to reduce expenditure of the formation energy but also to limit the inflow of bottom waters into the well.

Decrease of the pressure gradient at the well wall allows to minimize destruction of the bottom-hole area of the formation and to reduce carrying out of the small fractions of the reservoir rock which helps to extend the accident-free period of the well operation and to reduce operational costs.

The well diameter enlargement for elimination of the colmataged rock layers is also quite important. Mechanical impurity by the solid particles of drilling mud fluid and flushing fluid, degradation of the bottom-hole area properties in the process of cementing, impurity by solid particles containing in the filtering fluid and other reasons of the colmation of the reservoir rock may have significant influence on the well productivity. G.S. Pop, V.M. Kucherenkovskiy and P.A. Geresh have classified in their work the reasons of degradation of the capacity and filtration characteristics of the bottom-hole area \([28, 78]\):

- mechanical impurities;
- physicolithological;
- physicochemical;
- thermochemical.

Under conditions of the gas fields drilling-out, mechanical impurities are represented by solid particles of drilling mud fluid and flushing fluid. In the process of formation
Optimization of the Gas Wells Performance Indicators

Completion with a use of clay-water mud the level of formation impurity amounts 36-67 % in a month and 22-50 % in a year [29, 21-26]. At the West Siberia and Mangyshlak fields mud filtrate penetrates to the depth of 2-3 m for two days and of 8 m for 1-5 months because of the influence of the clay mud having water loss of 8-10 cm³/30 min. It results in degradation of permeability of the bottom-hole area of the formation by 1.6-22 times. Blocked permeability zone lies within the radius of 6.5-13.6 m. It is the opinion of V.I. Kudinov and B.M. Sutchkov that the well diameter enlargement by 2-3 times allows to recover natural permeability of the formation in the bottom-hole area almost completely [11, 80]. Enlargement of the well bore results in change of the rock stress state in the bottom-hole area and vertical stresses significantly reduce and can become lower than radial stresses. All these facts create conditions for opening of existing cracks and occurrence of new horizontal cracks along the bedding planes.

Formation unblocking occurs due to elimination of the pollution layer in the formation. It allows using the gas wells at lower draw-down pressure. In such a way the rate of water breakthrough to the wells decreases upon condition of bottom waters availability, pressure communication of formation and well increases through the whole thickness regardless of the layering rock heterogeneity, velocity of the filtering flow in the bottom-hole area stabilizes, as a result, possibility of water breakthrough to the well on separate sublayers reduces.

According to the studies of D.F. Boyarchuk and V.L. Kereselidze, depth of penetration of the bitumen-lime mud into formation was 20 – 60 cm when pore channels size is 100 mkm² [30, 25-27]. According to the data of SevKavNIPlGaz, OJSC, colmataged of the bottom-hole area of the gas formation results in degradation of permeability by 1.6 -22.5 times [26, 10-15]. Enlargement of the well diameter in the area of productive formation can completely or partially eliminate colmataged rock layer which allows to increase production.

To summarize, let us note that the technological practice of enlargement of the gas well diameter is the effective method of well production enhancement taking into account current macroeconomic environment with its prices for crude hydrocarbons and achievements of scientific and technological progress in the field of production of reamers. Optimization of the gas wells performance indicators by means of the bottom-hole area recovery is the promising direction for extension of the wells operation period and exploitation period of the field in whole.

REFERENCES


[7] Vratchev V.V. and Ingress in the Process of UGS Exploitation / V.V. Vratchev, E.N. Shafarenko, etc. // Gas industry, No. 11. – 1999


Optimization of the Gas Wells Performance Indicators


