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Flow Schematics When Opening Gas and Gas Condensate Fields by Horizontal Wells

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ABSTRACT: The paper presents the results of research in the field of horizontal wells application in the development of gas and gas condensate fields. Methods for schematizing the reservoir, determining the productivity of a horizontal gas well are described, factors affecting the flow rate of a horizontal well are listed.

I. INTRODUCTION

For a long time, the main method for extracting gas from productive formations was the drilling of fields with a system of vertical wells and their operation during development. In most cases, this method of opening proved to be justified, which was facilitated by good filtration and reservoir parameters, as well as their stability, and made it possible to operate wells with an economically acceptable flow rate.
However, in a number of cases, opening of reservoirs with a vertical wellbore leads to low production rates, rapid watering of the bottomhole zone of the wells, relatively large losses of condensate, deformation and destruction of the bottomhole zone when creating large drawdowns. In this regard, the development of gas fields in vertical wells with an insignificant reservoir thickness, low permeability, the presence of bottom water, as well as the development of shelf fields will be ineffective and will require the use of inclined and horizontal wells [1].

II. RELATED WORK

Almost all researchers involved in horizontal wells: Charny I.A., Aliev Z.S., Somov B.E., Zakirov S.N., Mishchenko I.T., Marakov D.A., Kotlyarova E.M., Borisov Yu.P., Tabakov V.P., Sada D. Joshi, Giger FM and others in their works emphasized that compared to vertical wells, when opening productive formations with a horizontal wellbore, the productivity of wells increases several times [2]. Many authors studying the problems associated with horizontal wells point to the following most significant reasons for drilling horizontal wells:
-significantly increases the production of formation fluid;
-a large, compared to opening with a vertical well, the geometry of the reservoir drainage zone is created, respectively, more specific drainage reserves per one well;
-the productivity of wells increases, and the effect of horizontal penetration is calculated in the presence of vertical fractures;
-operating conditions are created under which the component recovery of thin layers increases;
-the development of low-productivity formations becomes profitable, and the cost of drilling horizontal wells is comparable to the cost of vertical ones.
Currently, the following classification of horizontal wells has been adopted according to the radius of curvature-increasing the angle of inclination from the vertical section to the horizontal - wells with small, medium and large radius of curvature. Modern equipment and drilling technology makes it possible to open productive formations with small radius of a curved section $R_{curv}= 4 \div 12$ m, with medium and large radius of curvature $R_{curv}= 13 \div 150$ m and $R_{curv}> 150$ m, respectively [3]. Also in the works [4], [5], [6], [7], practical horizontal well design schemes are given.
The choice of one or another horizontal well design scheme is carried out depending on the shape and geometry of the productive reservoir, the composition and filtration and capacity properties of the fluid. The authors of the work [8] Z.S.

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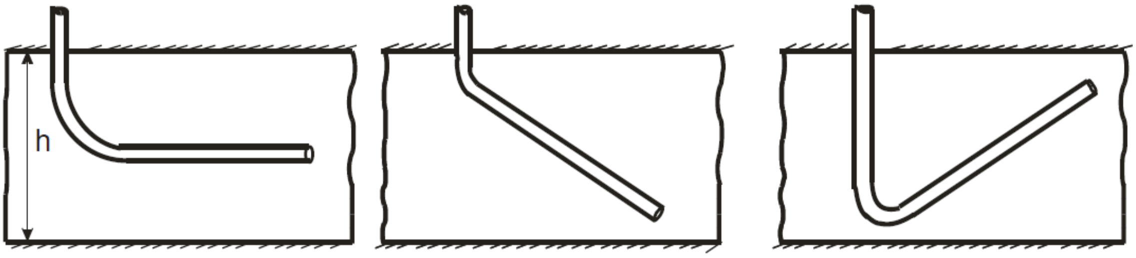
Aliev, E.M. Kotlyarova, L.V. Samuylova, D.A. Marakov. It is noted that the following horizontal wellbore profiles are currently basic: horizontal, descending, ascending and stepped.

The choice of the profile of the horizontal section of the well is influenced by the structure of the productive formation, the presence of heterogeneities, the composition and mechanical properties of the reservoir, the composition of the properties of the formation fluid, and the presence of fluid in it. In particular, it is recommended to open the reservoir:



a b c

Fig. 1. Opening schemes with a horizontal wellbore with different profiles: a - horizontal, b - descending with a single zenith angle, c - ascending with a single zenith angle

1. A horizontal profile (Fig. 1, a), if the reservoir is homogeneous, does not have vertical fractures, there is no liquid or has a low content, in the composition of the gas. In this case, the trunk should be located symmetrically in thickness. The asymmetric location of the horizontal wellbore, as practice shows, leads to an increase in the filtration resistance coefficients and a decrease in gas inflow from the top to the bottom;
2. Downward (Fig. 1, b), provides for the opening of all interlayers by the horizontal wellbore, which differ from each other in terms of reservoir parameters. This opening scheme has its drawbacks, in particular, with this type of opening, the minimum flow rate will be near the end of the wellbore, which will create the danger of sandy-clay plug accumulation in the specified area. The elimination of such a hazard requires equipping the descending section practically at the end of the barrel with fountain pipes. This, in turn, will lead to additional pressure losses along the horizontal section;
3. An ascending profile (Fig. 1, c), in the absence of the danger of flooding the well with bottom water and destruction of the bottomhole formation zone, and it is necessary to place the shoe of flowing pipes at the maximum possible distance from the lower sections of the formation, which excludes the possibility of formation of hydraulic locks in the curved section of the well. Such a scheme excludes the possibility of liquid and sand plugs formation in the horizontal section. The scheme is also relevant during the period of declining production in gas condensate fields, when the flow rates do not provide the limiting flow rate at which solid and liquid impurities are carried out.

The development of gas and gas condensate fields by horizontal wells creates the need for an analytical method of calculations to determine the parameters of wells and formations they penetrate, taking into account the influence of geological technical and technological factors on the completeness of the formation opening, on the distribution of pressure and temperature, etc. Description of gas filtration to a horizontal well, drainage zone of a horizontal well is a complex task with many variables in space and time. The authors of works devoted to schematization of inflow to a horizontal well are Charny I.A., Borisov Yu.P., Tabakov V.P., Aliev Z.S., Sheremet V.V. Giger F. contour radius, completeness of reservoir penetration, etc. In this regard, it is not always possible to obtain well parameters with the required accuracy, obtained from the dependencies determined by an approximate analytical method.

One of the assumptions made to solve the problems of fluid filtration to horizontal is the schematization of the drainage shape, which were taken in the form of a circle, ellipse and rectangle (Fig. 2). Bringing the real form of drainage to the correct forms indicated below depends on the extent of the influence of the horizontal well (finite or infinite formation), the degree of heterogeneity of the formation or interlayers, and permeability anisotropy. The above forms of drainage were studied by I.A. Charny, Yu.P. Borisov, Giger FM, Joshi SD Z.S. Aliev, B.E. The works [9], [10] and [11] show the dependence of the flow rate of a horizontal well depending on the forms of drainage. It should be noted that the works of Charny I.A., Borisov Yu.P., Giger FM, Joshi SD were devoted to determining the productivity of the well during filtration to a horizontal well of incompressible fluid, where a change in the volumetric properties of the formation fluid during filtration is excluded. Also, the inertial components of the resistance in the bottomhole zone arising at high inflow rates are not taken into account.

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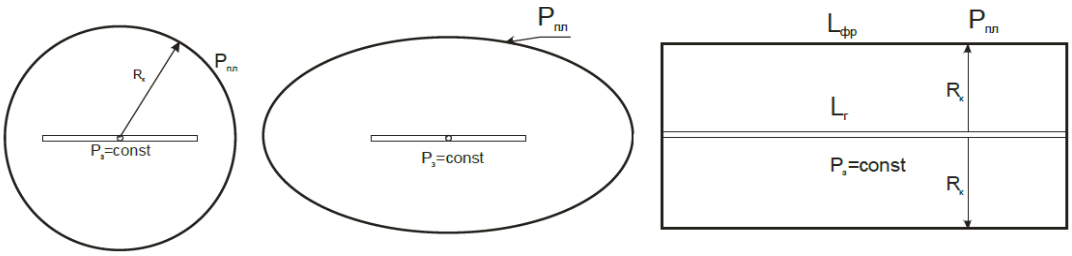

Fig. 2. Diagrams of the drainage zone shapes for a horizontal well: a-circular (according to Borisov and Tabakov); b-ellipsoidal (according to Giger, Saadi S. Joshi); in-rectangular (proposed by Z.S. Aliev)

Aliev Z.S. and Sheremet V.V. [12] proposed a description of the drainage zone in a rectangular shape when filtering gas to a horizontal well, and this shape becomes closer to the real shape and large errors in flow rate calculations are excluded in the case when there is no or no pressure change along the horizontal section of the well. practical significance.

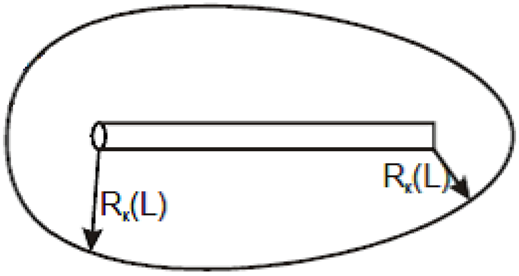

Fig. 3. The shape of the zone of the drained horizontal well, taking into account the change in bottomhole pressure along the length of the horizontal section of the wellbore: Rk (L) - the radius of the feed loop as a function of the length of the horizontal section of the wellbore

The true shape of the zone drained by a horizontal well provides for a change in bottomhole pressure and flow rate along the length of the horizontal section of the wellbore (Fig. 3). Accordingly, the radius of the drainage contour, as opposed to the drainage shape, will be variable.

III. METHODS

It is known that the flow of gas to the well occurs according to a nonlinear law of filtration, which in turn creates difficulties in the exact formulation of the solution to the problem, namely, in the representation of the filtration area from the horizontal section of the wellbore to its limits (radius of the drainage zone). So the true area of gas filtration is represented as such a fictitious area, where the total reservoir resistance is equivalent to the true resistance. In this case, the flow pattern to a horizontal well is divided into two zones (Fig. 4):

- at a distance $h_1 \leq R \leq R_k$, where $h_1 = H/2 - R_w$, filtration is plane-parallel;
- within $0 \leq R \leq h_1$, where $h(R) = \alpha + \beta\sqrt{R}$, which means the natural thickness of the reservoir is replaced by a fictitious variable thickness, and the well is replaced by a gallery with a height of $2R_w$. Here α and β are constant coefficients and are determined from the boundary conditions. For the case when the wellbore is equidistant from the top and bottom of the formation, these coefficients can be determined for a quarter of the shown scheme (Fig. 4), based on the boundary conditions: at $R=0$, $h=R_w$, at $R=h_1$, $h=R_w+h_1$. Then the coefficients: $\alpha=R_w$; β=and therefore

$$h(x) = R_w + \sqrt{h_1 R}, \qquad (1)$$

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For the adopted scheme in the second zone, the relationship between the pressure gradient and the gas production ratefor a quarter of the strip-like formation will have the following form:

$$\frac{\partial p}{\partial R} = \frac{\mu Z p_{at} T_r}{k p T_{st} L} \cdot \frac{Q^*}{(\alpha + \beta R^{0,5})} + \frac{\rho_{at} p_{at} T_r}{l L^2 T_{st} p} \cdot \frac{Q^{*2}}{(\alpha + \beta R^{0,5})^2}, \quad (2)$$

where μ *and* Z are the coefficients of viscosity and gas supercompressibility of the gas; k - permeability; ρ_{at} - gas density at standard conditions; l - coefficient of macro-roughness; L - the length of the horizontal well.

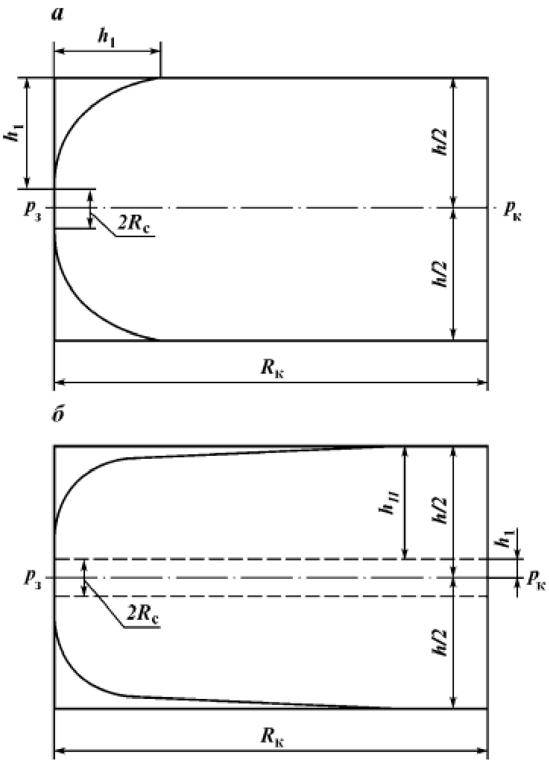

Fig. 4. Scheme of gas inflow to a horizontal well: a - with a parabolic nature of the change in h (R) in the bottomhole zone; b - with a hyperbolic nature of the change in h (R)

From Figure 4, it is easy to understand that considering the filtration area through fictitious, the entire filtration area of any section of the well is divided into 4 zones and with a symmetrical arrangement of the horizontal section of the wellbore, they will be equal.
Integrating (2) in the range from 0 to h_1 we get:

$$p^2 - p_{bh}^2 = \frac{2a^*}{L}\frac{2}{h_1}\left(h_1 + R_w ln\frac{R_w}{R_w + h_1}\right)Q^* + \frac{2b^*}{L^2}\frac{2}{h_1}\left(ln\frac{R_w + h_1}{R_w} - \frac{h_1}{R_w + h_1}\right)Q^{*2}, \quad (3)$$

$$a^* = \frac{\mu(P)\, Z(P,T)\, P_{ат} T_{пл}}{k(P)\, T_{ст}}, \qquad b^* = \frac{\rho_{ат}\, P_{ат} T_{пл}\, Z(P,T)}{l T_{ст}} \quad (4)$$

where a^* and $b^*$are the coefficients of filtration resistance without taking into account the geometry of the drainage zone by the well, which can be determined by studying exploration and also operating vertical wells, $\mu(P)$ and Z(P, T) are the coefficients of viscosity and compressibility of gas in reservoir conditions; T_r, T_{st} - reservoir and standard temperatures; k(P) and l - coefficients of permeability and macroroughness of the porous field; R_k is the distance to the border of the zone drained by a horizontal well with a radius of R_w; h1 - thickness determined by the formula h1 = h/2 – R_w; h is the gas-saturated formation thickness; L is the length of the horizontal section of the wellbore, taken equal to L=L_{fr}, where L_{fr} is the length of the strip-like fragment of the deposit (Fig. 4).

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For the first zone, considered as a zone of plane-parallel filtration, the relationship between flow rate and pressure:

$$p_k^2 - p^2 = \frac{2a^*}{L}\left(\frac{R_k-h_1}{R_k+h_1}\right)Q^* + \frac{2b^*}{L^2}\left(\frac{R_k-h_1}{(R_w+h_1)^2}\right)Q^{*2} \quad (5)$$

Considering that $Q^* = Q/4$ (where Q is the flow rate of a horizontal well), and adding equations (3) and (5), for the entire reservoir we obtain:

$$p_k^2 - p_{\text{bh}}^2 = \frac{a^*}{2L}\left[\frac{2}{h_1}\left(h_1 + R_w ln\frac{R_w}{R_w+h_1}\right) + \frac{R_k-h_1}{R_k+h_1}\right]Q \; + \frac{b^*}{8L^2}\left[\frac{2}{h_1}\left(ln\frac{R_w+h_1}{R_w} - \frac{h_1}{R_w+h_1}\right) + \frac{R_k-h_1}{(R_w+h_1)^2}\right]Q^2 \quad (6)$$

If we introduce the designation a_h and b_h, we get the dependencies:

$$a_h = \frac{a^*}{2L}\left[\frac{2}{h_1}\left(h_1 + R_w ln\frac{R_w}{R_w+h_1}\right) + \frac{R_k-h_1}{R_k+h_1}\right],$$
$$b_h = \frac{b^*}{8L^2}\left[\frac{2}{h_1}\left(ln\frac{R_w+h_1}{R_w} - \frac{h_1}{R_w+h_1}\right) + \frac{R_k-h_1}{(R_\kappa+h_1)^2}\right] \quad (7)$$

Coefficients a_h and b_h in equation (7) are determined under the condition that in the near-wellbore zone the change in filtration thickness is parabolic. With a hyperbolic nature of the change in the filtration thickness:

$$a_h = \frac{\mu(P)\,Z(P,T)\,P_{\text{at}}T_{\text{пл}}}{2L\,k(P)\,T_{st}}\left[\frac{R_k}{\alpha_1} + \frac{\beta_1}{\alpha_1^2}ln\frac{R_k+2R_w-\beta_1/\alpha_1}{2R_w-\beta_1/\alpha_1}\right],$$
$$b_h = \frac{\rho_{\text{ат}}\,P_{\text{ат}}T_{\text{пл}}\,Z(P,T)}{8L^2 l T_{\text{ст}}}\left[\frac{R_k}{\alpha_1^2} + \frac{2\beta_1}{\alpha_1^3}ln\frac{R_k+2R_w-\beta_1/\alpha_1+h_1}{2R_w-\beta_1/\alpha_1} + \frac{\beta_1^2}{\alpha_1^4}\cdot\left(\frac{1}{2R_w-\beta_1/\alpha_1} - \frac{1}{R_k+2R_w-\beta_1/\alpha_1}\right)\right] \quad (8)$$

where $h_1 = h/2 - R_w$; $\alpha_1 = R_w + \nu\alpha$; $\beta_1 = \nu\beta$ (9)

$$\alpha = \frac{[h-2R_w]\cdot(R_k+2R_w)}{2R_k}; \quad \beta = \alpha\cdot 2R_w \quad (10)$$

ν-reservoir permeability anisotropy.

IV. RESULTS

The disadvantage of determining the coefficients of filtration resistance by formulas (7) and (8) is the averaging of the filtration capacitive properties of the reservoir and the properties of the fluid saturating it over the entire identified fragment of the reservoir. The dependencies themselves assume that within the zone limited by the fragment length and supply loops, the reservoir properties of the rock (porosity, permeability saturation) and the fluid are assumed to be constant, which excludes the possibility of taking into account local disturbances, local heterogeneities, the presence of interlayers (horizons) hydrodynamically unconnected between themselves.
The authors, who proposed formulas (1) and (2) for determining the coefficients of filtration resistance, Aliev Z.S., Sheremet V.V., as well as Marakov D.A., Kotlyarova E.M., Samuylova L.V. it is noted that today, in order to obtain accurate results on the indicators of both the well and the entire field, it is necessary to carry out numerical calculation methods and build hydrodynamic models of the reservoir [13]. Numerical calculation methods, as well as equations based on numerical calculation methods, describe gas filtration to the bottomhole as a three-dimensional non-stationary filtration with a nonlinear law of resistance, taking into account the forces of gravity and phase transitions. Along with the fact that numerical calculation methods have lower errors and assumptions compared to approximate calculation methods, they require a large amount of initial data to create a three-dimensional model of a reservoir, which can be difficult at the initial stage of development.

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V. CONCLUSION

The approximate method for calculating the parameters of a horizontal gas well, taking into account the nonlinear filtration law, is the basic method, although it is inferior in the accuracy of the results to numerical methods, which allows at the design stage of field development:
-calculate the specific drainage reserves per horizontal well;
-to obtain the flow rate of a horizontal gas well located in an anisotropic strip-like formation at an arbitrary distance from its top and bottom;
-calculate the productivity of the well taking into account the pressure losses in the horizontal part of the wellbore and select its optimal design;
-to plot the dependence of the horizontal well flow rate on the degree of penetration of the strip-like formation;

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