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Improvement of well drainage radius calculation

Lubkov Michail[1], Zakharchuk Oksana[2]*

[1] Poltava Gravimetric Observatory Institute of Geophysics by S.I. Subbotin
name National Academy of Sciences of Ukraine https://orcid.org/0000-0002-2680-9508
[2] National University «Yuri Kondratyuk Poltava Polytechnic» https://orcid.org/0000-0002-4229-1964
* Corresponding author E-mail: oksana.zakharchuk@nupp.edu.ua

The calculation of well drainage radius is improved on the example of Chervonozayarske gas field. Theoretical research methods are applied, which include a systematic analysis of the information used, numerical modeling based on the combined finite element-difference method, methods of visual representation of the information obtained, analytical methods To increase the accuracy of the calculation of the well drainage radius, the heterogeneity of the porous medium structure was taken into account. It is established that the drainage radius of a gas well expands with time. This allows to determine the optimal grid of production wells, the number and location of injection wells to ensure their interaction, and hence ¬ reduce material costs in the gas industry

Keywords: drainage radius, field development, gas production well, mathematical modeling

Удосконалення розрахунку радіуса дренування свердловини

Лубков М.В.[1], Захарчук О.О.[2]*

[1] Полтавська гравіметрична обсерваторія Інституту геофізики ім. С.І. Субботіна
Національної академії наук України
[2] Національний університет «Полтавська політехніка імені Юрія Кондратюка»
*Адреса для листування E-mail: oksana.zakharchuk@nupp.edu.ua

Радіус дренування свердловини є важливим параметром для розробки нафтогазових родовищ, а також дослідно-промислової експлуатації свердловин. Інформація про радіус дренування свердловини є вирішальною для визначення оптимальної сітки видобувних свердловин, кількості та розташування нагнітальних свердловин для забезпечення їх взаємодії, проектування методів впливу на привибійну зону пласта для розрахунку необхідного об’єму робочої рідини. Тому метою проведеного дослідження є удосконалення розрахунку радіусу дренування свердловини на прикладі Червонозаярського газового родовища. Для проведення дослідження застосовано теоретичні методи: системний аналіз використаної інформації, чисельне моделювання на основі комбінованого скінчено-елементно-різницевого методу, методи візуального подання отриманої інформації, аналітичні методи. Застосування математичного моделювання шляхом розв’язку рівняння п’єзопровідності Лейбензона комбінованим скінчено-елементно-різницевим методом дозволяє враховувати неоднорідну будову пористого середовища по площі пласта та на його границях. Це дає змогу адекватно на кількісному рівні описувати розподіл нестаціонарного пластового тиску навколо газовидобувної свердловини. За допомогою застосування аналітичної формули по значеннях середніх пластових та вибійних тисків розраховано радіуси контуру живлення свердловини при різних термінах розробки пласта. Згідно з отриманими результатами, радіус дренування свердловини 468-В(D) Червонозаярського газового родовища розширюється з часом. Ця інформація може бути використана для проєктування більш розрідженої сітки свердловин, що може призвести до зниження матеріальних затрат в газовидобувній промисловості. Результати проведеного дослідження є корисними при складанні проєктів розробки родовищ та дослідно-промисловій експлуатації свердловин

Ключові слова: радіус дренування, розробка родовища, газовидобувна свердловина, математичне моделювання

Introduction

The well drainage radius is an important parameter for oil and gas field development as well as pilot well operation. Information about the well drainage is crucial for determining the optimal grid of production wells, the number and location of injection wells to ensure their interaction, designing methods of influencing the bottomhole zone of the formation to calculate the required volume of working fluid [1].

That is why the refinement of the calculation of the well drainage radius of the production well is an urgent task for oil and gas engineering and technology.

Review of the research sources and publications

In the literature it is possible to find the calculation of the well drainage radius as a value that does not depend on time and is a function only of the total fluid production, porosity and thickness of the formation [2, 3]. This is a rather conditional definition of the area from which oil, gas or condensate is produced [4].

To be able to adequately solve various practical problems, the well drainage radius should be considered as a dynamic value that depends on the intensity of filtration processes in the formation (and hence - on the depression). In such cases, it is possible to use analytical methods [5], but this imposes restrictions on the value of porosity and formation thickness [6]. In addition, it is necessary to neglect many important parameters for the possibility of calculation [7].

Therefore, the use of numerical methods is the main tool for creating a universal method for determining the radius of well drainage. Today, there are a large number of developed models for the «reservoir-fluid» system, which allow calculating at different parameters of the porous medium: fractured rocks [8], shale formations [9, 10], carbonate reservoirs [11].

Definition of unsolved aspects of the problem

To improve the accuracy of calculating the drainage radius of a well, it is important to take into account the heterogeneous structure of the porous medium, since this clearly affects the distribution of reservoir pressures, and hence the intensity of the filtration process.

Therefore, it is of interest to apply the combined finite element-difference method (CFEDM) of resolving nonstationary anisotropic piezoconductivity Lebenson problem, with calculation of heterogeneous anisotropic filtration parameters in the gas reservoirs and gas penetration in its boundaries, has a good convergence and steadiness of problem resolving [12]. So it allows adequately calculate pressure distribution near gas production wells in anisotropic hard reaching reservoirs in real exploitation conditions and has some advantages in comparison with another methods.

The results of the mathematical modeling of the filtration process by applying the CFEDM allow us to estimate the value of the well drainage radius, taking into account the complex geological structure of the formation.

Problem statement

Therefore, the purpose of the work is:to refine the calculation of the well drainage radius based on the mathematical modeling of the distribution of reservoir pressure using the CFEDM.

To achieve this goal, theoretical research methods were applied, which include a systematic analysis of the information used, numerical modeling based on the CFEDM [12], methods of visual representation of the information obtained, analytical methods.

Basic material and results

The study was carried out on the example of the Chervonozayarske Gas Field (Ukraine). In the mathematical formulation of the problem, the following assumptions are made. The effective reservoir thickness is constant and much less than the horizontal dimensions of the reservoir, in this case the problem is considered as two-dimensional. Permeability, porosity, viscosity and gas compressibility factor, initial reservoir pressure, flow rate are known and constant values over time. The task is calculated for a single-phase flow (gas). Then [12]:

$$\frac{\partial P^2}{\partial t} = \frac{kP_0}{\mu m}\left(\frac{\partial^2 P^2}{\partial x^2} + \frac{\partial^2 P^2}{\partial y^2}\right) + \gamma, \qquad (1)$$

$$P(t=0) = P_0, \qquad (2)$$

$$k_b gradP^2 = \alpha(P^2 - P_b^2), \qquad (3)$$

where (2) – the piezoconductivity equation;
(3) – initial condition;
(4) – the limiting condition for fluid infiltration at the boundaries of the area under consideration;
k – the permeability of the gas phase, m^2;
μ – the dynamic viscosity of the gas, Pa·s;
m – the porosity of the gas-bearing reservoir, fractions of units;
P_0 – the initial pressure of the porous layer, Pa;
α – the fluid infiltration coefficient at the boundaries of the area under consideration, m;
P_b – the pressure at the boundaries of the area under consideration, Pa;
k_b – the permeability of the gas phase at the boundaries of the area under consideration, m^2.

The algorithm for calculating the system of equations (1)–(3) by the finite element difference method is described in [12].

To solve the system of equations (1)–(3), the simulated area is divided into 81 finite eight-node elements. As a result of solving the Leibenson piezoconductivity equation using the combined finite element difference method, let's obtain the pressure value at all nodal points of the finite element mesh. Based on the found nodal values, the pressure is determined at an arbitrary point in the hydrocarbon reservoir of the study area at a given point in time. Area-weighted reservoir pressure is determined from isobar maps.

The results of modeling the reservoir pressure distribution around the well allow to draw conclusions about the drainage radius by applying an analytical formula for determining the flow rate of a gas well [13]. Since the value of the flow rate is known, from here it is possible to find out the value of the gas drainage radius:

$$Q = \frac{\pi kh(P_{av.r}^2 - P_b^2)}{\mu P_{atm} \ln \frac{R_c}{r_s}} \Rightarrow \ln R_c = \frac{Q\mu P_{atm}}{\pi kh(P_{av.r}^2 - P_b^2)} + \ln r_w, \quad (4)$$

where Q – the flow rate of the well, thousand m^3/s;
μ – the coefficient of dynamic viscosity of the gas, mPa·s;
P_{atm} – atmospheric pressure, $P_{atm} = 0.1$ MPa;
k – the permeability coefficient, μm^2;
h – the effective thickness of the reservoir, m;
r_w – the summary radius of the well, m;
$P_{av.r}$ – average reservoir pressure based on simulation results, MPa;
P_b – bottom hole pressure according to simulation results, MPa;
R_c – well drainage radius, m.

The summary radius of the well is determined according to [14]:

$$r_s = r_w e^{-(C_1 + C_2)}, \quad (5)$$

where r_w – the radius of the well along the bit, mm; C_1 and C_2 are imperfection coefficients according to the degree and nature of disclosure, respectively.

$$C_1 = \frac{1}{\bar{h}} \ln \bar{h} + \frac{1 - \bar{h}}{\bar{h}} \ln \frac{\delta}{\bar{r}_w} + \frac{1}{\bar{h}}, \quad (6)$$

where $\bar{h} = h_0 / h_{ef}$ – the relative opening of the reservoir by the well; $\delta = 1.6(1 - \bar{h}^2)$; $\bar{r}_w = r_w / h$ – the relative radius of the well.

$$C_2 = \frac{h_{ef}}{nR_0} + \frac{h_{ef}^2}{3n^2 R_0^2}, \quad (7)$$

where n – the number of perforations; R_0 – the hole radius; h_{ef} – effective reservoir thickness.

The coefficient of dynamic viscosity of gas at atmospheric pressure is calculated from the known composition of the gas, the calculation is made at reservoir temperature, and then recalculated at reservoir pressures according to [14].

For the maximum approximation of the reservoir model to real conditions, excellent permeability values were set in the place of tectonic excitation [15].

The initial data for the results of the study are given in Table 1.

Let's assume that the opening of the productive stratum of the V-26-T-1a horizon of the Chervonozayarske Gas Field was carried out with a bit with a diameter of 215.9 mm. Then the diameter of the well along the bit is d_w = 215.9 mm, respectively, the radius is r_w = 107.95 mm. The coefficient of imperfection by the nature of the opening will have to be neglected due to the lack of inreservoir on the perforation of the bottom hole.

The summary radius of well 468-B(D) is calculated in Table 2.

The critical and pseudocritical parameters of the gas well 468-B(D) of the Chervonozayarske Gas Field are calculated in Table 3, where x_i – the mole fraction and gas component; P_{abs} and T are critical parameters and gas components (table values); $P_{cr.i} = x_i \cdot P_{abs}$ and $T_{cr.i} = x_i \cdot T$ – pseudocritical parameters of the i-th gas component.

The results of the study in Fig. 1 shows the change in the distribution of reservoir pressure near the production well ($P_{av.r}$ and P_b – the value of the average reservoir and bottom hole pressure, respectively, MPa). Fig. 1 does not show the entire reservoir area of 3.76 km^2 (1939×1939 m), but a zone close to the well (with an area of 950×950 m), where there is an intense pressure change.

The recalculation of the coefficient of dynamic gas viscosity according to the instructions [14] for various values of average reservoir pressures is given in Table 4.

The calculation of the value of the gas drainage radius for different periods of well operation 468-B(D) according to the formula (5) is given in Table 5.

Table 1 − Initial data for modeling

Name, designation	Value	Units
Gas reservoir area S	3,76	km^2
Porosity factor m	0,11	–
Initial reservoir pressure P_0	$42,1 \cdot 10^6$	Pa
Reservoir temperature T_r	386	K
Coefficient of dynamic gas viscosity μ at P_0 та T_f	$0,027 \cdot 10^{-3}$	Pa·s
Compression coefficient of the rock skeleton β_2	10^{-10}	Pa^{-1}
Average well production rate Q	60,3	thousand m^3/day
Effective gas-saturated reservoir thickness h_{ef}	3,7	m
The total thickness of the productive layer h_{calc}	56	m
Permeability coefficient k	0,3	μm^2
Reservoir gas saturation coefficient β	0,72	s

Table 2 − Calculation of the summary radius of the well 468-B(D)

$\bar{h} = h_0 / h_{ef}$	$\delta = 1.6(1-\bar{h}^2)$	$\bar{r}_w = r_w / h$	C_1	r_s, m
0,066	1,593	0,0019	54,84	0,0015

Table 3 − Calculation of pseudo-critical parameters of gas well 468-B(D)

Gas composition	x_i, %	Critical parameters		Pseudocritical parameters	
		P_{abs}, kgf/cm^2	T, K	$P_{cr.i}$, kgf/cm^2	$T_{cr.i}$, K
CH_4	0.9612	46.95	190.55	45.1283	183.1567
C_2H_6	0.0116	49.76	306.43	0.5772	3.5546
C_3H_8	0.0203	43.33	369.82	0.8796	7.5073
n-C_4H_{10}	0.0012	38.71	425.16	0.0465	0.5102
i-C_4H_{10}	0.0004	37.19	408.13	0.0149	0.1633
n- C_5H_1	0.0003	34.35	469.65	0.0103	0.1409
i-C_5H_{12}	0.0002	34.48	460.39	0.0069	0.0921
CO_2	0.0040	75.27	304.20	0.3011	1.2168
N_2	0.0004	34.65	126.26	0.0139	0.0505
He	0.0004	2.34	5.20	0.0009	0.0021
				P_{cr} =46.9796 kgf/cm^2 or 4.6071 MPa	T_{cr} =196.3944 K

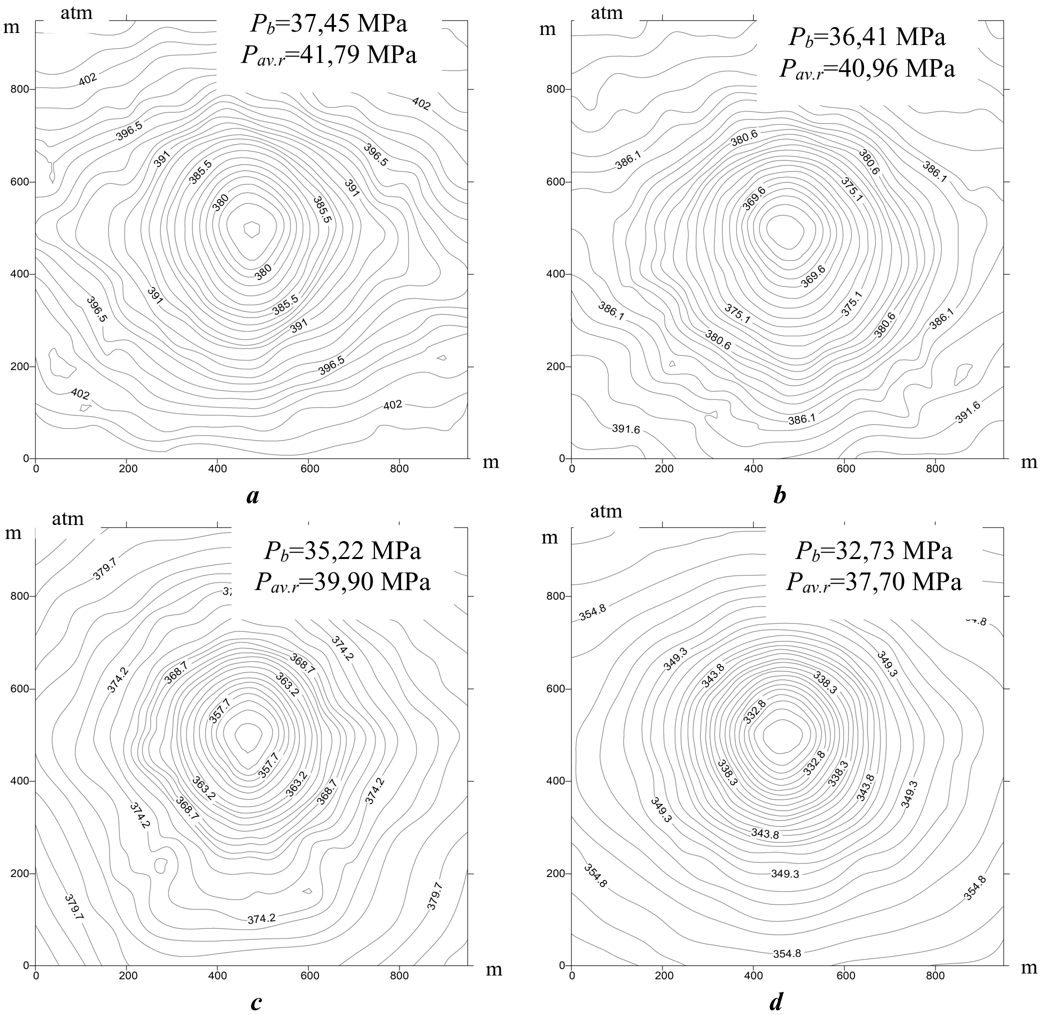

Figure 1 – Pressure distribution fields around well 468-B(D) at different operating times:
a – 10 days; b – 50 days; c – 100 days; d – 200 days

Table 4 − Gas viscosity calculation for well 468-B(D) at reservoir pressures

Well operation life *t*, days	Average reservoir pressure $P_{av.r}$, MPa	$P_{pr} = P_{av.r} / P_{cr}$	μ, cP (calculation according to [14])
10	41,79	9,07	0,027
50	40,96	8,89	0,027
100	39,90	8,66	0,028
200	37,70	8,18	0,029

Table 5 − The value of the well drainage radius 468-B(D)

Well life 468-B(D), days	Average reservoir pressure according to the results of modeling $P_{av.r.i}$, MPa	Bottom hole pressure according to the results of modeling $P_{b.i}$, MPa	Gas dynamic viscosity coefficient μ_i, mPa·s	The value of the well drainage radius $R_{c.i}$, м
10	41,79	37,45	0,027	286,56
50	40,96	36,41	0,027	289,44
100	39,90	35,22	0,028	293,27
200	37,70	32,73	0,029	301,78

Conclusions

To solve the non-stationary inhomogeneous Leibenson filtration problem, a combined finite-element-difference method was applied. This makes it possible to take into account the heterogeneous distribution of reservoir characteristics of the reservoir (in the framework of this study, zonal heterogeneity was set by a different value of the permeability coefficient at the site of tectonic disturbance of the reservoir).

Using the applied method, it is possible to adequately describe the pressure distribution in a gas-saturated reservoir, opened by a production well, at a quantitative level.

Using the reservoir pressure distribution fields obtained as a result of modeling, the value of the well drainage radius was calculated. Clarification of the calculation of the well drainage radius is useful for field development projects and pilot operation of wells.

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