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Determination of the exact daily gas intake according to the level of formation completion in the underground gas storage

Określenie dokładnego dziennego poboru gazu w zależności od stopnia udostępnienia formacji w podziemnym magazynie gazu

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ABSTRACT: This article derives the formula for the exact daily gas intake of a gas-dynamic incomplete flatbed gas injection well according to the level of formation completion in the underground gas storage (UGS). In natural gas fields and underground gas storages, the formation is incompletely saturated with hydrocarbons due to the level of completion of the formation. In the upper part of the formation there is a flat-radial simple leakage flow through the gas well, and in the unopened part there is a complex curved radial flow. Separate formulas have been developed for the exact daily volume consumption of hydrocarbon gas injected into these wells. For this purpose, gas dynamics problems for two different stationary gas flows have been solved. By adding up the daily volume of gas consumption according to these formulas, the formula of full daily consumption for replaced well No. 2 was obtained. Which is equal to the exact full daily volume consumption of flatbed well No. 1. Fluids and gases are known to enrich the water supply and field system. The boundaries of the latter are the contours of the pressure and the flow. The water pressure in the reservoir was determined by changing the sum of the volume of the cavity at the edge of the reservoir, the capacity of the created gas and the amount of injected gas.

Key words: underground gas storage (UGS), reservoir penetration degree, gas dynamic imperfections, flat-bottomed well, investment, cone bit, flat-radial flow, hemispherical-radial flow, curvilinear-radial flow.

STRESZCZENIE: W artykule wyprowadzony został wzór na dokładny dzienny pobór gazu z odwiertu gazowo-energetycznego z niepełnym zasilaniem gazem, w zależności od stopnia udostępnienia formacji w podziemnym magazynie gazu (PMG). W przypadku złóż gazu ziemnego i podziemnych magazynów gazu formacja jest nie w pełni nasycona węglowodorami z uwagi na poziom jej wypełnienia. W górnej części formacji występuje prosty przepływ płasko-radialny przez odwiert gazowy, a w części nieudostępnionej przepływ jest znacznie bardziej skomplikowany i ma charakter zakrzywionego przepływu radialnego. Opracowano oddzielne równania dla dokładnego dziennego zużycia objętości gazu węglowodorowego zatłaczanego do tych odwiertów. W tym celu wykorzystano zagadnienia dynamiki gazu dla dwóch różnych stacjonarnych przepływów gazu. Po zsumowaniu dziennego zużycia gazu zgodnie z tymi wzorami otrzymano formułę pełnego dziennego zużycia dla wymienionego odwiertu nr 2. Jest ono równe dokładnemu dziennemu zużyciu gazu przez dany odwiert płaskodenny nr 1. Jak wiadomo, płyny i gazy wzbogacają układ zasilania wodą i system terenowy. Granicami tych ostatnich są kontury ciśnienia i przepływu. Ciśnienie wody w zbiorniku zostało określone poprzez zmianę sumy objętości ubytku w brzeżnej części zbiornika, objętości wprowadzonego gazu i ilości wtłoczonego gazu.

Słowa kluczowe: podziemny magazyn gazu (PMG), stopień udostępnienia złoża, imperfekcje dynamiczne gazu, otwór płaskodenny, nakłady, świder gryzowy, przepływ płasko-radialny, przepływ hemisferyczno-radialny, zakrzywiony przepływ radialny.

Introduction

Since the viscosity of natural hydrocarbon gas in the reservoir conditions is many times lower than the viscosity of oil, its filtration rate is much higher than that of oil. The development of oil and gas from shale and tight reservoirs requires substantial capital investment and represents a cooperative effort from different disciplines, such as exploration, drilling, completion, and production operation to achieve the desired outcome. It is known that wells are drilled with drill bit. When a flatbed well is put into operation, two different leakage flows occur in the underground gas storage (UGS) formation:

- flat-radial simple in the upper part of the layer opened;
- in the unopened lower part of the layer, there is a complex, i.e. a curved hemispherical radial flow.

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The goal of the work

The task of underground gas storage systems is to compensate for seasonal and daily demand peaks. As with mineral oil, this buffer function is being increasingly backed up by strategic storage for times of crisis. Storage systems could, however, be employed for a further purpose in the future, namely for the storage of synthetic natural gas obtained from excess wind and solar power. The exact debit formula for an incomplete flatbed well in oil fields has not yet been developed, but approximate formulas have been made (Jafarov et al., 2013; Ismayilov et al., 2018). However, no attempt has been made to do so in natural gas fields or underground gas storage facilities (UGS) and there is no information in the literature (Rasulov, 2008; Aliyeva, 2018). This article offers a very interesting way to solve this problem.

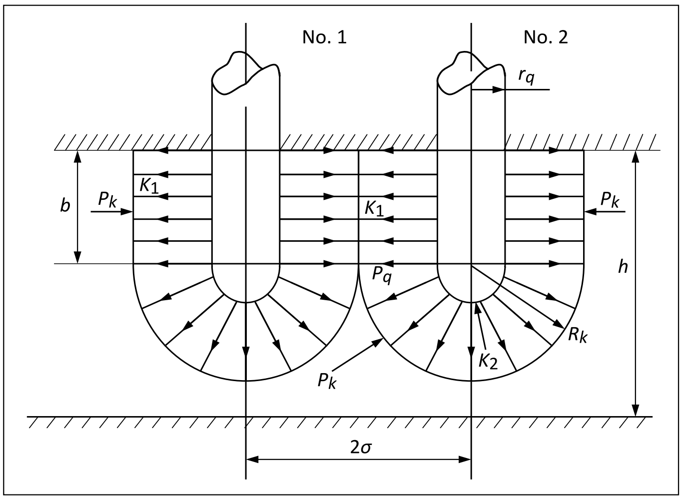

Figure 1. Schematics of two wells of different profiles according the level of formation completion in the underground gas storage (UGS): well No. 1 – flat bottom; well No. 2 – bottom with a concave hemispherical surface

Rysunek 1. Schematy dwóch odwiertów z różnymi profilami w zależności od stopnia udostępnienia formacji w podziemnym magazynie gazu (PMG): odwiert Nr 1 – płaskie dno; odwiert Nr 2 – dno z wklęsłą półkulistą powierzchnią

Figure 1 shows a schematic of two unfinished wells of different profiles according to the level of formation completion in the underground gas storage (UGS).

In the figure, the gas injection well No. 1 has a flat bottom; the borehole No. 2 has a concave hemispherical surface.

The following symbols are assumed in the picture:
R_k – radius of the feeding contour,
r_q – radius of the gas injection well,
h – thickness of underground gas storage layer,
b – thickness of the exposed part of the layer,
2σ – thickness of the exposed part of the layer,
P_k – layer pressure,
P_q – dynamic well pressure,
K_1 – conductivity of the opened upper part of the layer,
K_2 – permeability coefficient of the unopened part of the formation on well No. 2.

It should be noted that in the underground gas storage (UGS), the gas flow from the formation to the gas production well occurs in the formation, and in the injection well, the gas flow occurs in the opposite direction – the direction of flow turns 180 degrees (Aliyeva, 2016, 2019).

Performance of work

To solve the problem with the proposed method, flat-bottomed gas injection well No. 1 is replaced by a well with a concave hemispherical surface No. 2. In doing so, the simple flat-radial at the open top of the layer remains unchanged; in the unopened lower part of the layer, the complex flow changes and the hemispherical radial becomes a simple filtration flow; where curved radial gas flow lines become hemispherical radial straight lines. Filtration process in both parts of the formation on well No. 2 linearly obeys Darcy's law (Miralamov et al., 2013; Mustafayev et al., 2017). Let's look at the stationary flow of gas from the injection well to the reservoir in the underground gas storage:

$$r\rho\upsilon_q = \text{const} \tag{1}$$

We can assume and write the following expressions for filtering speed and density:

$$\upsilon_q = -\frac{k}{\mu_q}\frac{dp}{dr}; \ \rho = ap$$

then we can write the expression (1) as follows:

$$-r\frac{dp^2}{dr} = C_1 \tag{2}$$

$$-\frac{dp^2}{dr} = \frac{C_1}{r}$$

$$-dp^2 = C_1\frac{dr}{r}$$

$$-p^2(r) = C_1 \ln r + C_2 \tag{3}$$

For C_1 and C_2 we use the following boundary conditions to find the integral constants.

$$r = r_q \ \text{ when } \ P(r_q) = P_q \ \text{ happens,}$$
$$r = R_k \ \text{ when } \ P(R_k) = P_k \ \text{ happens.}$$

Then the following equations can be written from expression (3):

$$P_q^2 = C_1 \ln r_q + C_2$$
$$P_k^2 = C_1 \ln R_k + C_2$$

we find here:

$$C_1 = \frac{P_q^2 - P_k^2}{\ln \frac{r_q}{R_k}}$$

$$C_2 = P^2 - \frac{P_q^2 - P_k^2}{\ln \frac{r_q}{R_k}} \ln R_k$$

Substituting these values of the integral constants in formula (3), we obtain the pressure distribution:

$$P(r) = \sqrt{P_q^2 + \frac{P_q^2 - P_k^2}{\ln \frac{r_q}{R_k}} \ln \frac{r}{R_k}} \quad (4)$$

The pressure gradient will be as follows:

$$\frac{dp}{dr} = -\frac{P_q^2 - P_k^2}{2\pi\, p(r) \ln \frac{r_q}{R_k}} \quad (5)$$

Then the current filtration rate will be:

$$\upsilon_{\text{gaz}} = -\frac{k}{\mu_q}\frac{dp}{dr} = \frac{k\left(P_q^2 - P_k^2\right)}{2\mu_{\text{gaz}}\, r p(r) \ln \frac{r_q}{R_k}} \quad (6)$$

The daily volume consumption of gas entering the gas storage of the injection well 2 will be:

$$Q_1 = \frac{\rho}{\rho_0}\frac{\upsilon_q}{r} = r_q 2\pi h R_k = \frac{\rho}{\rho_0} 2\pi r_q \frac{k}{\mu_{\text{gaz}}}\frac{dp}{dr}\frac{r}{r_q}$$

$$\frac{\rho}{\rho_0} = \frac{p}{p_0}$$

If we accept, we get for daily gas consumption:

$$Q_1 = \frac{\pi K_1 h\left(P_q^2 - P_k^2\right)}{\rho_0 \mu_{\text{gaz}} \ln \frac{r_q}{R_k}} \quad (7)$$

Now we determine the daily consumption of hydrocarbon gas injected from the injection well No. 2 into the unopened part of the reservoir (Aslanov, 2001).

Here, the area of the current hemisphere filtration surface will be:

$$F_2 = 2\pi r^2$$

The daily gas consumption from the unopened lower part of the well No. 2 to the underground gas storage will be as follows:

$$Q_2 = \frac{\rho}{\rho_0}\upsilon_{\text{gaz}} \Big| r = r_q 2\pi r^2 \frac{K_2}{\mu_{\text{gaz}}}\frac{dp}{dr}\Big|_{r=r_q}$$

Here $\rho/\rho_0 = p/p_0$ we assume:

$$Q_2 = \frac{P}{P_0} 2\pi r_q \frac{K_2}{\mu_{\text{gaz}}} r^2 \frac{dp}{dr} \quad (8)$$

$$\frac{Q P_0 \mu_{\text{gaz}}}{2\pi r_q K_2}\frac{dr}{r^2} = P dp$$

If we integrate this equation, we get (8):

$$Q_2 = \frac{\pi r_q K_2\left(P_q^2 - P_k^2\right)}{\mu_{\text{gaz}} P_0 \left(\frac{1}{r_q} - \frac{1}{R_k}\right)} \quad (9)$$

The total daily volume consumption of gas injected from well No. 2 to the underground gas storage (UGS) will be as follows:

$$Q = Q_1 + Q_2 = \frac{\pi}{\mu_{\text{gaz}} P_0}\left(\frac{K_1 h}{\ln \frac{r_q}{R_k}} + \frac{K_2 r_q}{\frac{1}{r_q} - \frac{1}{R_k}}\right)\left(P_q^2 - P_k^2\right) \quad (10)$$

Conclusion

The only difference between well No. 1 and well No. 2 is that they have different geometric shapes of the bottom of the well, so the other relevant parameters of these two wells are assumed to be equally valuable in order to get the right result from the solution of the problem (Mustafayev et al., 2019).

Therefore, the daily volume of gas injected from well No. 2 will be the full daily gas consumption of wellbore No. 1.

Results and suggestions

1. The article determines the exact daily gas intake volume of an unfinished flatbed gas injection well according to the level of formation completion in the underground gas storage (UGS).
2. In natural gas fields and underground gas reservoirs, gas dynamics is incomplete due to the opening of the reservoir, i.e. the reservoir is not complete, open the outlet on top of it.
3. In the upper part of the formation there is a flat-radial simple leakage flow through the injection wells, and in the unopened part there is a complex curved radial flow. The law of filtration in this case is the law of linear filtration.
4. A formula has not yet been developed for the exact daily consumption of hydrocarbon gas injected into such wells.
5. Here, an unconventional new method has been proposed in order to solve the problem correctly, i.e. the flat well No. 1 has been replaced by a gas well No. 2 with a concave hemispherical surface shape.
6. In order to create the same geological and physical conditions for these two different profile gas wells, the numerical values of all relevant parameters are equal.

7. Two different stationary hydrodynamic theoretical problems have been solved for the replaced gas injection well No. 2, and separate formulas have been developed for the daily volume consumption of gas injected into the open and unopened parts of the formation.
8. Combining these two daily gas consumption solutions, a formula is obtained for the full daily gas consumption of well No. 2, which will be the formula for the full daily gas consumption of well No. 1.

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Nomenclature

R_k – radius of the feeding contour,
r_q – radius of the gas injection well,
h – thickness of underground gas storage layer,
2σ – the thickness of the exposed part of the layer,
P_k – layer pressure,
P_q – dynamic well pressure,
K_1 – conductivity of the opened upper part of the layer,
K_2 – permeability coefficient of the unopened part of the formation,
v_q – filtering speed,
ρ – density,
C_1, C_2 – integral constants,
P – pressure,
Q – volume consumption of gas,
F – area of the filtration surface.

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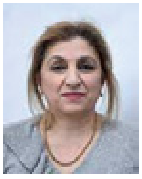

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