Simulating Filtration to Evaluate Hydrodynamic Indices of the Underground Gas Storage Operation

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Abstract

The research objective is to develop and test mathematical model of gas storage in the layered aquifer with poorly permeable interlayer if plane-parallel and axisymmetric filtration takes place. The paper evaluates the gas-hydrodynamic operational indices of the underground gas storages within aquifers in the South East Ukraine. Comprehensive approach has been applied involving collection, systematization, and analysis of actual data on filtration and physicomechanical properties of enclosing rocks impacting formation of natural and technogenic deposits as well as analytical and numerical methods to solve equations of the gas-water contact shift under different conditions. A gas-hydrodynamic model of underground gas storage within the nonuniform aquifer has been substantiated to calculate its cyclic operation in the three-layered seam taking into consideration crossflows through a poorly permeable stopping. The calculation results show significant impact of characteristics of the layered porous environment on the gas water contact transfer through certain seams. The derived new technique linearizing a system of differential equations to identify pressure within a reservoir is generalization of the earlier applied procedures with introduction of 'boundary schemes'. The calculation results demonstrate significant impact of the layered porous environment on the gas water contact transfer through certain seams. The findings may be applied while making evaluations at the stage of gas storage design within aquifers.

Keywords: *aquifer, gas storage, filtration, gas water contact, nonuniformity*

Introduction

Along with the necessity to develop alternative energy sources, stable operation of fuel and energy complex of Ukraine depends heavily upon the reliable functioning of the unified gas supply system involving production facilities to mine, transport, store, and distribute gaseous hydrocarbons. A significant feature of the system is complete interconnection of its components expressed by changes in operation conditions of the system if working conditions of its certain object varies. In such a way, nonuniform gas consumption may result in its interrupted recovery while demanding the development of underground gas storages (UGSs) within the deposits of aqueous rock as well as mathematical models able to calculate hydrodynamic indices of their operations under different geological and technological conditions [1–5].

The earlier considered [5–6] hydrodynamic models of UGSs were obtained while assuming piston nature of water displacement with gas. Such a schematization of the process is popular and completely justified in many cases [7–8]. Nevertheless, optimum ratio between buffer gas volume and active one, and determination of coefficients of gas saturation and average weighed pressure for different aquifer zones cannot be identified in terms of a piston problem formulation.

The problem has been solved partially under Backley-Leverett theory; numerous papers concern it (for example, [9–10]). The essential point is as follows: in this context, gas saturation distribution has been determined under constant initial conditions irrespective of solution for gas which makes it it possible to simplify drastically the calculation procedure. However, the abovementioned complicates interpretation of the calculation results since the undefined pressure prevents from recalculation of gas amount within the seam to the normal conditions. In this connection, the paper objective is to substantiate the methods determining the basic hydrodynamic UGS indices in terms of its cyclic operation based upon a two-phase filtration model, and determination of the average weighed pressure and gas saturation within different storage zones.

Research material and methods

Dynamics of cyclic water displacement with gas is analyzed within a uniform infinite reservoir. A radial displacement case is considered. It is anticipated that in terms of degassing, mass discharge of gas $\rho_{at}G(t)$ is known and gas saturation at the well is constant. Gas is extracted until R(t) front, having a high water saturation value, approaches the well.

It is also anticipated that the displacement process forms three typical zones (Fig. 1): 1st being a zone with high average gas saturation σ_1 limited by a circle with R(t) radius; 2nd being a zone with low average gas saturation $\sigma_2<\sigma_1$; and 3rd being a zone inflated with pure water $\sigma(x,y)=0$. Since pressure within a high average gas saturation zone is almost equal to pressure within R(t) front, we assume that pressure in the 1st zone depends only upon time. We also assume that within the 2nd and 3rd zones, pressure follows the equation of elastic liquid filtration.

Pressure distribution within the 2nd and 3rd zones is identified using a method of 'fictive' sources and drainages [11]. Thus, we have

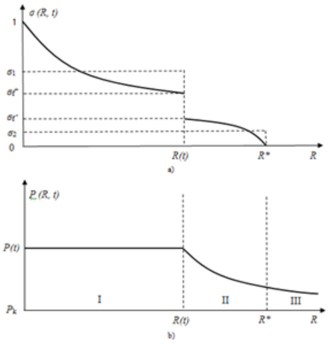

Fig. 1. Diagrams to calculate gas saturation (a) and pressure (b) within a horizontal aquifer

Rys. 1. Diagramy do obliczania nasycenia gazem (a) i ciśnienia (b) w poziomej warstwie wodonośnej

$$P_{at}\int_0^t G(t)dt = \tilde{P}(t)\int_0^t Q(t)dt - \frac{Q(t)\bar{\sigma}_2\mu_v}{K}\left(\frac{R^2}{2}\ln\left(\frac{R^{*2}}{R(t)^2} - \frac{1}{4}(R^{*2} - R^2(t))\right)\right), \quad (1)$$

where P_k is pressure at infinity; μ_v is water viscosity; k, h, and a are permeability, thickness, and piezoconductivity of a seam; and $Q_0(\tau)$`is specific rate of a 'fictive' source located in the central share of a seam.

Within the 1st boundary, $P_f(R(t),t)$ pressure and hence average weighed P(t) pressure is determined relying upon equation (1)

$$\bar{P}(r,t) = P_k + \frac{\mu_v}{4\pi kh}\int_0^t \frac{Q_0(\tau)}{(t-\tau)} exp(-R^2(t)/(4a(t-\tau)))\, d\tau, \quad (2)$$

The specific rate of a 'fictive' source $Q_0(\tau)$ is selected in such a way to equalize at the r = R(t) front consumption on the left and right of the boundary. Within the 1st zone, the total Q(t) consumption is constant along the whole area (under the assumption on incompressibility of phases being filtered) inclusive of R(t) boundary. From the 2nd zone, Q(t) consumption may be derived using equation (1). Hence, to identify specific rate of the 'fictive' source, we have following integral equation

$$Q(t) = 2\pi R(t)h\left(-\frac{k}{\mu_v}\frac{\partial P}{\partial r}\right)_{r=R(t)} = \frac{R^2(t)}{4a}\int_0^t \frac{Q_0(\tau)e^{-\frac{R^2(t)}{4a(t-\tau)}}}{(t-\tau)^2} d\tau \quad (3)$$

A law of R(t) front advance is known from saturation solution [11]

$$R^2(t) = \frac{f'(\sigma^+)}{\pi mh}\int_0^t Q(t)dt, \quad (4)$$

where f'(σ+) is the derived Backley-Leverett function applied for gas saturation within the front; and m is a seam porosity.

Equation of gas balance is used to close (1)-(4) system.

$$P_{at}\int_0^t G(t)dt = \bar{P}(t)\pi R^2(t)mh\bar{\sigma}_1 + \int_{R(t)}^{R^*} P(r,t)2\pi hrm\bar{\sigma}_2 dr \quad (5)$$

P(r,t) function, located under integral in expression (5), is determined from ratio (1). However, in view of the 2nd limitedness, it is possible to apply simpler logarithmic pressure distribution corresponding to uncompressible liquid filtration

$$P(r,t) = \tilde{P}(t) - \frac{Q(t)\mu_v}{2\pi kh}\ln\frac{r}{R(t)}, \quad (r > R(t)). \quad (6)$$

Having inserted ratio (6) into equation (5) and calculated the integral in the right side, we will obtain

$$P(r,t) = P_k + \frac{\mu_v}{4\pi kh}\int_0^t \frac{Q_0(\tau)}{(t-\tau)} exp(-r^2/(4a(t-\tau)))\, d\tau, \quad (7)$$

where G(t) is consumption of gas injected into the seam under the standard conditions.

It should be mentioned that the simplification, connected with substitution of expression for P(r,t), is not of principal nature; thus, ratio (1) can be used for equation (5) during numerical implementation.

Introduce dimensionless variables

$$x = \frac{t}{T};\ \tilde{p} = \frac{\tilde{P}}{P_k};\ \zeta = \frac{\tau}{T};\ q = \frac{Q\mu_v}{P_k hk};\ q_0 = \frac{Q_0\mu_v}{P_k hk};\ \alpha = \frac{R^2}{4aT}, \quad (8)$$

where T is typical process life; as a rule, it is equal to a year.

Owing to the use of the introduced variables, (2)-(4), and (7) expression will look like

$$\tilde{p}(x) = 1 + \frac{1}{4\pi}\int_0^x \frac{q_0(\zeta)e^{-\frac{\alpha(x)}{x-\zeta}}}{x-\zeta} d\zeta, \quad (9)$$

$$q(x) = \alpha(x)\int_0^x \frac{q_0(\zeta)e^{-\frac{\alpha(x)}{x-\zeta}}}{(x-\zeta)^2} d\zeta, \quad (10)$$

$$\alpha(x) = \beta f'(\bar{\sigma}^+)\int_0^x q(x)dx, \quad (11)$$

$$\gamma W = \tilde{p}(x)\int_0^x q(x)dx - \frac{q(x)}{4\pi\beta}\left(\alpha^*\ln\frac{\alpha^*}{\alpha} - (\alpha^* - \alpha)\right), \quad (12)$$

Assume that injection and withdrawal follow a harmonic law.

(9)-(12) ratios are the closed system of integral equations to identify p(x), q(x),q_0(x),and α(x). In this context, σ_1, σ_2, and σ+ values are determined along with solving a problem for saturation [11].

Then single out and consider separately three specific stages of UGS operation: initial gas injection into the undisturbed aquifer; extraction; and gas injection into the seam during a random cycle of UGS operation.

Initial gas injection into the undisturbed aquifer. If gas is injected into the undisturbed aquifer then gas saturation distribution is represented by means of the known Backley-Leverett solution [12]; zone 2 (Fig.1) is not available, R*=R(t). In this regard, the saturation jump R(t) is defined using the ratio

$$R^2(t) = \frac{f'(\sigma^+)}{2\pi kh}\int_o^t Q(\tau)d\tau. \quad (12)$$

Gas saturation σ+ within R(t) front is determined by means of the transcendental equation solution

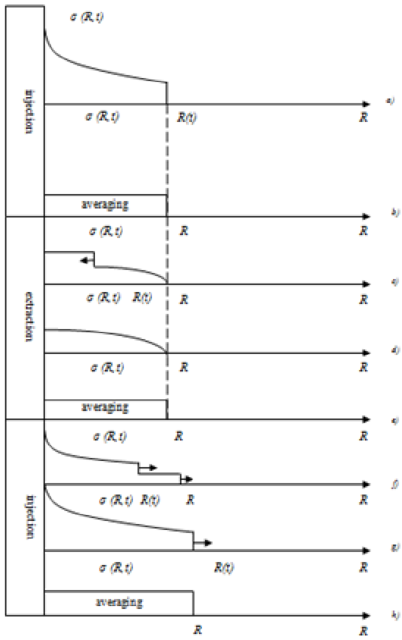

Fig. 2. On the calculation of gas saturation under cyclic UGS operation

Rys. 2. Obliczenia nasycenia gazem przy cyklicznej pracy PMG

$$\frac{f(\sigma^+)}{\sigma^+} = f'(\sigma^+) \qquad (13)$$

Average gas saturation is identified from the ratio

$$\bar{\sigma}_1 = \frac{1}{f'(\sigma^+)} \qquad (14)$$

Assume for the numerical (9)-(12) system that within $X_{j-1} \leq X \leq X_{j-1} + \Delta X_j$ moment, q(x) and q0(x) functions are constant. Subsequently, (9)-(12) equations for the specified time interval may be represented as follows

$$q_j(X) = \frac{\gamma w(X) - \acute{p}_j(x)\sum_{i=1}^{j-1} q_i \Delta x_i}{\acute{p}_j(x)\Delta X_j}; \qquad (15)$$

$$\alpha_j(x) = \beta f'(\sigma^+)\sum_{i=1}^{j} q_i \Delta x_i; \qquad (16)$$

$$q_{oj}(x) = (q_j - \sum_{i=1}^{j-1} q_{0i}\,(e^{-\frac{\alpha_j}{x-x_{i-1}}} - e^{-\frac{\alpha_j}{x-x_i}})e^{\frac{\alpha_j}{\Delta x_j}} \qquad (17)$$

$$\acute{p}_j(x) = 1 + \frac{1}{4\pi}\sum_{i=1}^{j-1} q_{0i}(-E_i(-\frac{\alpha_j}{x-x_{i-1}}) + E_i(-\frac{\alpha_j}{x-x_i})). \qquad (18)$$

W(x) function is given by the expression

$$W(x) = 0.5(1+\cos(2\pi x)). \qquad (19)$$

Analytical model for the case looks like: W(x) is the initial value to solve (15)-(18) system. The value is determined through ratio (19). While inserting W(x) into (15) and setting p'j*(x) value, to a first approximation, it may be specified as that one being equal to p'_{j-1}. Identify $q_j(x)$ value. (16)-(18) ratios help define successively α_j, q_{oj}, and p'_j values. In general, the latter does not coincide with p'j*. New approximation of p'j* is selected; the iteration process continues until p'j* matches p'j with the specified E accuracy. The final p'j(x) value, calculated for the time interval, also defines $q_j(x)$ and $\alpha_j(x)$ values corresponding to it.

Gas extraction during a random cycle. As it has been mentioned above, according to the accepted planning, gas is extracted until saturation jump with a coordinate nears a well placed in the central share of the seam. In this context, volume of the gas, extracted from Q_k^* seam, may be defined as well as normalized to the reservoir conditions. Then, relying upon the specified harmonic selection law, it becomes possible to identify gas consumption normalized to the reservoir conditions

$$q(x) = -\frac{\pi Q_H^*}{T}\sin(2\pi(x - x_N)) \qquad (20)$$

In this case, the equation takes the form

$$\alpha_j(x) = \alpha^* - \beta f'(1 - \sigma_f)\sum_{i=N}^{j} q_i \Delta x_i \qquad (21)$$

where α* is the maximum α(x) value achieved during gas injection; N is number of x_N time moment corresponding to the extraction start; and 6_f is front value of gas saturation in terms of k[th] extraction.

Since q(x)value is entered by means of (20) then $\alpha_j(x)$, $6_{oj}(x)$, and p'j(x) values may also be identified through direct computation using formulas (16), (18), and (21); $W_j(x)$value is defined using the formula

$$W_{j(x)} = \frac{1}{\gamma}(\bar{p}_j(x)\sum_{i=1}^{j} q_i \Delta x_i - \frac{q_i}{4\pi\beta}(\alpha^* ln\frac{\alpha^*}{\alpha} - \alpha^* + \alpha). \qquad (22)$$

In such a way, while extracting, W_j is not the initial (specified) value. It is determined during the problem solving. The abovementioned depends upon the selected operational schedule of UGS. In the context of the schedule, gas extraction is maximum possible and volume of gas, remained in the seam, is minimal.

Under reservoir conditions $\bar{Q}_k^*$, front saturation value σf as well as the extracted gas volume is determined through the solution analysis for saturation [13].

If the extraction takes place within a random k[th] cycle, then solution for saturation is divided into two cases:

1. In terms of $0 < \sigma'_2 < \sigma_n$ (where σ_n is gas saturation corresponding to Backley-Leverett bending point function) case,

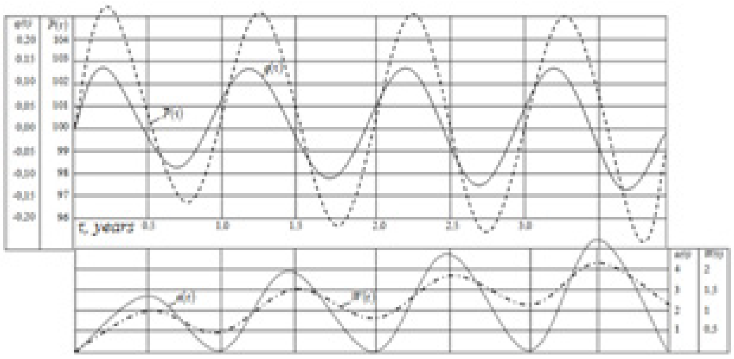

Fig. 3. Calculation example of hydrodynamic indices of UGS operation in terms of a cyclic mode

Rys. 3. Przykład obliczeń wskaźników hydrodynamicznych pracy PMG w trybie cyklicznym

volume of gas $Q_к^*$, extracted from a seam during k[th] cycle, is identified using the expression

$$Q_3 = \int_{x_{N+1}}^{x_{N+2}} q(x)dx. \tag{23}$$

2. If $\sigma_n < \sigma_2' < 1$ then $Q_к^*$ determination should involve gas saturation assessment within σf front by means of the transcendental equation solving

$$\frac{f(\overline{\sigma}_2')-f(\sigma_f)}{\overline{\sigma}_2' - \sigma_f} = f'(\sigma_f) \tag{24}$$

While applying the determined σf value, the following is defined

$$Q_к^* = \beta \sum_{i=1}^{N} q_i \Delta xi – \alpha^*(\sigma_f - \frac{f(\sigma_f)}{f'(\sigma_f)}) \tag{25}$$

At the end of the extraction, average gas saturation value σ_2 is defined with the help of the formula

$$\overline{\sigma}_2 = \overline{\sigma} - \frac{Q_к^*}{\alpha^*} \tag{26}$$

Moreover, it is taken up as the initial distribution at the start of following injection (Fig. 2 c, d, and e).

Gas injection within a random k+1st cycle. Within a random cycle, gas injection into UGS differs from its initial injection in the fact that there is some gas saturation distribution in the seam; for the case, it is substituted for a constant σ_2 value. During injection, the seam demonstrates two gas saturation jumps with R(t) and R* coordinates as well as corresponding dimensionless variables α(x) and α* (Fig. 2, f).

In this case, expression (15), determining mass balance in the UGS, will take the form

$$q_j(x) = \frac{\gamma W_j(x) - \overline{p}_j(x)\sum_{i=1}^{j-1} q_i \Delta x_i}{\overline{p}_j \Delta x_j - (\frac{\overline{\sigma}_2}{4\pi\beta})(\alpha^* ln\,(\frac{\alpha*}{\alpha_j}) - \alpha* + \alpha_j)}. \tag{27}$$

The unknowns q_{0j}, α_j, and p_j are identified from (16)-(18) ratios. (1)-(18), and (27) system is solved similarly to the initial injection case. Law of $W_j(x)$ variation is taken up as follows

$$W_j(x) = W_0 + 0.5W_{к+1}\,(1 – cos(2\pi(x - x_N))) \tag{28}$$

where W_0 is amount of gas in the seam before previous extraction is over; $W_{к+1}$ is amount of gas injected in the seam during active injecting; and x_{N+1} is starting point of the active injective.

If gas is injected within a random cycle, the saturation solution depends upon the injected gas volume (under the reservoir conditions)

$$Q_к^* = \beta \sum_{i=1}^{N} q_i \Delta xi – \alpha^*(\overline{\sigma}_2' - \frac{f(\overline{\sigma}_2')}{f'(\overline{\sigma}_2')}) \tag{29}$$

Having determined the value of front gas saturation σ_f from the ratio

$$\frac{f(\sigma_f)-f(\overline{\sigma_2})}{\sigma_f - \overline{\sigma_1}} = f'(\sigma_f), \tag{30}$$

and having identified 'critical' value of the injected gas volume

$$Q_{cr} = \frac{\alpha^*}{\beta}\frac{\overline{\sigma_2}}{(\overline{\sigma_2} f(\sigma_f) - f(\overline{\sigma_2}))}, \tag{31}$$

consider two probable solution alternatives:

1. Assume that Q_3 value is less than critical volume Q_{cr}; then motion of two saturation jumps takes place within the seam. In this context, before injection is over, maximum zone the maximum zone with gas α^*_{N+2}, is (Fig. 2, f)

$$\alpha_{N+2}^* = \alpha_{N+1}^* + \beta Q_3 f'(\overline{\sigma_2})/\overline{\sigma_2}. \tag{32}$$

Amount of gas within the seam as well as average gas saturation until injection is over will be defined as follows

$$Q_{N+2} = Q_{N+1} + Q_3, \tag{33}$$

$$\sigma_1 = \beta Q_{N+2} / a^*_{N+2} \tag{34}$$

σf value, being a part of equation (17), is defined from (30) ratio.

2. If $Q_3 > Q_{cr}$ then frontal gas saturation value is identified by solving the equation

$$\beta(\sigma_f f'(\sigma_f) - f(\sigma_f) + 1)Q_3 - \overline{\sigma_2}\alpha^*_{N+1} = \beta Q_3 \tag{35}$$

In addition, geometry of zone with gas before injection is over α^*_{N+2} is defined from the ratio

$$\alpha^*_{N+2} = \beta Q_3 f'(\sigma_f) \tag{36}$$

Q_{N+2} and σ_1 values are determined from (33) and (34) expressions.

Case two solving for injection arises if one saturation jump is in the seam (Fig. 2, g). It should be mentioned that the initial injecting stage will always involve case one; consequently, if a back edge α(x) nears and passes α* ($Q_3 > Q_{cr}$) front case two may happen (Fig. 2, f, g).

The considered algorithm to solve the formulated problem has been represented based upon approximate solution for saturation [9]. It is possible to examine similar solution algorithm for the case when saturation is solved relying upon accurate statement [16]. Comparative analysis of two solutions, performed on the basis the processed calculation results, has shown their good agreement for the first six operational UGS cycles. Computation for more prolonged period, based upon a model with averaging, results in significant errors. However, simple implementation and short period, required to make the calculations, help recommend the methods while making multivariant computations of a gas storage transfer to cyclic operation.

Results and their analysis

The represented algorithm has been implemented in the software environment Mapple for a hypothetic case. The seam parameters were specified as follows: $\kappa = 10^{-12}$ m² being permeability; m = 0.2 being porosity; a = 1 m²/s being piezoconductivity coefficient; h = 10 m being seam thickness; $\mu v = 10^{-3}$ Pa·s being formation water viscosity; $P\kappa$ = 9.8 MPa being pressure within the undisturbed seam boundary; and period of the complete operational UGS cycle being T = 1 year = $3.15 \cdot 10^{7}$ s (four three month periods: injection – idle time –extraction – idle time). The calculations involved the idea that one and the same gas mass G_3 is injected into the seam during any period. Mass of the extracted Gext gas was defined during the solution.

Phase penetrations for gas $k_g(\sigma)$ and water $k_w(\sigma)$, involved by Backley-Leverett functions , i.e. f(σ)

$$f(\sigma) = \frac{k_g \mu_g}{k_g \mu_g + k_w \mu}$$

were assumed as follows according to paper [10]

$$\begin{cases} k_g(\sigma) = \left(\frac{\sigma - 0.1}{0.9}\right)^{3.5} (4 - 3\sigma), (0.1 \le \sigma \le 1) \\ k_w(\sigma) = \left(\frac{0.8 - \sigma}{0.8}\right)^{3.5}, \ (0 \le \sigma \le 0.8) \end{cases}$$

where σ is gas saturation.

Fig. 3 shows the calculation results. Curve I is dimensionless gas consumption under the formation conditions q(τ); II is change in average weighed pressure in the seam P(τ); III is change in space of pores with gas having high average gas saturation α(τ); and IV is volume of gas in the seam normalized to the standard conditions. Analysis of the data explains that pressure in UGS during the operation transfers to a cyclic mode rather rapidly; moreover, amplitude changes in terms of pressure variations during different cycles are not higher than several percent. In this context, formation pressure excess over a reservoir boundary while gas injecting is 5% (P = 10.3 MPa). Subsequently, when following idle period is over the pressure equalizes ($P = P\kappa$); in the period of gas extraction, formation pressure is 3–5% less than its boundary pressure (P = 9.5-9.3 MPa) depending upon the operational UGS cycle.

Dimensionless gas consumption under the formation conditions, being the ratio between product of its viscosity consumption and boundary pressure product per seam thickness and permeability, also increases up to 0.13 while injecting. It is almost matches 1100 m³/day gas consumption. During following idle time, gas consumption decreases vanishing to the period end. By the end of extraction stage, gas flow rate increases annually. It was 0.08 (-678 m³/day) in the first year; 0.11 (-932 m³/day) in the second year; 0.13 (-1100 m³/day); and 0.14 (-1185 m³/day). It should be mentioned that after gas extraction and following idle time, its consumption was equal to zero again.

By the end of injection period, dimensionless space of pores with gas as well as during following idle time increased cycle by cycle. It was 2.5 in the first year; 4 in the second year; 4.8 in the third year; and 5.2 in the fourth year. The values correspond to a radius of a reservoir zone differing in high gas saturation, i.e. 17.7; 22.4; 24.5; and 25.6 km. In this regard, values of gas volume within the seam normalized to the standard conditions correspond to 1; 1.5; 1.8; and 2.1, respectively. It is also possible to mention a phase shift between W(τ) and q(τ) arising owing to the availability of elastic zone III (Fig. 1) with the formation liquid being contracted.

Conclusion

Numerical hydrodynamic model of underground gas storage within a horizontal aquifer has been developed; the model takes into consideration two-phase nature of liquid and gas filtration. Processing of the obtained results has made it possible to substantiate the approximate method calculating formation gas volume, consumption, and pressure at different stages of storage development as well as during its operational cycles. According to the calculation results in the software environment Maple for a hypothetic case, it has been identified that gas pressure in the storage transfers to a cyclic mode rather quickly under a minor (i.e. several percent) amplitude change during different cycles. In this context, formation pressure excess over a reservoir boundary while gas injecting is 5%; in the period of gas extraction, formation pressure is 3–5% less than its boundary pressure. In the injection period, gas consumption is almost constant; in turn, its flow rate during extraction increases year by year. In addition, space of pores with high average gas saturation also increases annually.

The proposed methods calculating the basic hydrodynamic UGS parameters in aquifers make it possible to identify the optimum ratio between buffer gas volume and active one in the storage as well as determine the fundamental technical and economic indicators of its operation at the design stage. The abovementioned may be applied to make business plans and investment proposals concerning seasonal accumulation of gaseous hydrocarbons in the natural environment. Further research is expedient to test adequacy of the developed methods while comparing the obtained calculation results with actual operational data of the operating UGSs.

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Symulacja filtracji w celu oceny wskaźników hydrodynamicznych podziemnego magazynowania gazu

Celem badań jest opracowanie i przetestowanie modelu matematycznego magazynowania gazu w warstwie wodonośnej ze słabo przepuszczalną międzywarstwą, przy założeniu filtracji płasko-równoległej i osiowo-symetrycznej. W artykule dokonano oceny gazowo-hydrodynamicznych wskaźników eksploatacyjnych podziemnych magazynów gazu w warstwach wodonośnych południowo-wschodniej Ukrainy. Zastosowano kompleksowe podejście polegające na zebraniu, usystematyzowaniu i analizie rzeczywistych danych, dotyczących właściwości filtracyjnych i fizykomechanicznych skał otaczających, wpływających na powstawanie osadów naturalnych i technogenicznych, a także analityczne i numeryczne metody rozwiązywania równań przesunięcia kontaktu gaz-woda w różnych warunkach. Model gazowo-hydrodynamiczny podziemnego magazynowania gazu w niejednorodnej warstwie wodonośnej został uzasadniony w celu obliczenia jego cyklicznej pracy w pokładzie trójwarstwowym z uwzględnieniem przepływów krzyżowych przez słabo przepuszczalną zaporę. Wyniki obliczeń wskazują na istotny wpływ charakterystyk warstwowego środowiska porowatego na kontakt gazu z wodą przez określone pokłady. Nową techniką linearyzującą układ równań różniczkowych do identyfikacji ciśnienia w zbiorniku jest uogólnienie wcześniej stosowanych procedur poprzez wprowadzenie „schematów brzegowych". Wyniki obliczeń wskazują na istotny wpływ warstwowego środowiska porowatego na kontakt gazu z wodą przez określone pokłady. Uzyskane wyniki mogą być wykorzystane przy dokonywaniu ocen na etapie projektowania magazynów gazu w warstwach wodonośnych.

Słowa kluczowe: *warstwa wodonośna, magazynowanie gazu, filtracja, kontakt gazu z wodą, niejednorodność*