Proceedings of IMM of NAS of Azerbaijan, 2010, vol. XXXIII (XLI), pp. 179-182. _ 179

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ESTIMATING ACTIVE GAS IN UNDERGROUND GAS STORAGES SUBJECT TO ADSORPTIONAL PROPERTIES OF A RESERVOIR AND INTERFORMATIONAL CROSS FLOW CONDITIONS

Abstract

One of the important factors of effective functioning of undergraund gas storage (UGS) is regulation of amount of injected and extracted gas.

Certain estimation of capacity of pore space and also calculation of amount of active and buffer gas in connection with its effusion and adsoption allows to exclude contradictions in the process of seasonal gas supply industrial and consumer services systems.

In the paper a new method for estimating gas loss as a result of effusion and adsorption processes in formation systems is given applied and analytic solution methods of the stated problem are reduced.

Underground gas storages (UGS) formed mainly in porous reservoirs of rocks, water-bearing beds, depleted gas, gas-condensate and oil pools serve for regulating seasonal irregularities of gas consumption, solution of strategic problems in extremal situations. Efficiency of UGS operation is mainly determined by degree of interchangeability of liquid and gas in inhomogeneous porous media in periods of injection and extraction of gas from a storage. Discrepancy of the volume of injected and extracted gas is stipulated by the peculiarities of geological structure of UGS objects that are characterized by inhomogeneity both in area and section. Under cyelic use, ignorance gas retained and crossflowing to upper gas streak may reduce to incorrect estimation of active gas volume and this reduces to extraction of some part of buffer gas. As a result, the gas extracting wells will intensively go to water.

In the present paper, the effects arising in the process of adsorption and overflows from apper layers of gas-saturated formatiens are estimated on an example of Garadaq UGS.

Owing to many reasons both of geological (failure in formation top) and technological character in due course gas may overflow from underground storage to upper lying layers and may crop out to surface with all undesirable consequences). Under these regular leakages, gas loss becomes significant and this lowers economic efficiency of the storage.

Formation pressure satisfies a heat-conductivity equation with boundary conditions on a moving boundary surface a circle of variable radius $R(t)$. There are no exact analytic solutions for $R_0(0) \neq 0$ up to now. It is difficult to obtain numerical solutions by using ECM, but ther may represent interest for verification of suitability of approximate solutions. Some automodel solutions for $R_0(0) = 0$ are given in [1]. For $R_0(0) \neq 0$ practical calculations at injection and extraction of gas may be conducted with using solutions and diagrams of elastic filtration regime problem for $R = Const$.

Partitioning the time and intervals into intervals we may assume that change of R_0 from interval to interval happens by jumps whose size may be determined from the material balance.

The authors of the paper [2], give an approximate but very satisfactory method for such calculations based on the method of sequential change of stationary states

(SCSS). In calculations, owing to small viscosity of gas with sufficiently exactuess degree the pressure in the storage is also considered constant.

For $R_0(t) \le r \le R_k(t)$ pressure distribution follows from Dupui law

$$P = P_k - \frac{P_k - P(t)}{\ln \frac{R_k}{R_0}} \ln \frac{R_k}{r} \tag{1}$$

where $P(t) = P$ is absolute pressure of gas in the storage, $R_0(t)$ is a radius of the storage, $V_H(t)$ is gas volume in the storage refered to normal conditions, t is time whose sone of depression extended to the length $R_k(t)$ with pressure p_k.

Allowing fr gas saturation G and elasticity of formation E, the authors of [2] suuggest to write formula (1) in the form:

$$\pi m\sigma h\left[R_0^2(t) - R_0^2(0)\right] = \frac{\pi mh}{k}\left[p(t) - p_k\right]\left[\frac{P_k^2(t) - R_0^2(t)}{\ln \frac{R_k(t)}{R_0(t)}} - R_0^2(t)\right], \tag{2}$$

where the right hand side of the formula represents increase of elastic reserve in the formation calculated in pressure increase. At the first approximation it is accepted that:

$$R_k^2(t) - R_0^2(t) = 4at, \quad a = \frac{k\widehat{E}}{m\mu_B} \tag{3}$$

where k is a mean permeability factor; μ_B is viscosity of water under formation conditions.

Knowing $P(t)$, one can determine the gas volume $V_H(t)$ as:

$$V_H(t) = \pi m\sigma h R_0^2(t) \frac{P(t)}{z(t) P_{k\tau}} \tag{4}$$

Finding $R_0^2(t) = 4a\,t\alpha = \frac{4Ek\tau\alpha}{m\mu_B}$ we estimate gas volume of the storage in water-bearing formation: $V_H(t) = \pi\sigma h R_0^2 \frac{E_k}{\mu_k} t\alpha \frac{P(t)}{z(t)P_{k\tau}}$. Here, by the given relation $\frac{E\sigma}{\Delta P}$ we find the value $\alpha = \frac{R_0^2(t)}{4at}$ form the dependence $\frac{E\sigma}{\Delta P} \sim \alpha$ grap cited in [2].

In estimating and regulating gas volume we can't ignore its adsorption in formation grains.

It is known that adsorbed gas is desorbed showerly than buffer gas from gas-liquid mixture.

For estimating the volume of the sorbed gas, the process of gas diffusion into formation rock may be represented by a diffusion and kinetics equation under appropriate initial and bondary conditions [3].

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2}, \quad 0 < x < l, \quad 0 < t < T, \tag{7}$$

$$C(x,t)|_{t=0} = C_1(x) = Ae^{-x}, \tag{8}$$

$$\left.\frac{\partial C(x,t)}{\partial t}\right|_{x=0} = C_2(t), \quad 0 < t < T, \tag{9}$$

$$\left.\frac{\partial C(x,t)}{\partial t}\right|_{x=L} = \frac{1}{T}\left[C(x,t) - a\left(P(x,t)\right)\right]_{x=L} \equiv C_3(t), \tag{10}$$

where a is a sorption isotherm that functionally depends in $P(x,t)$.

It follows from (8) and (9) that:

$$C(x,t)|_{x=0} = A + \int_0^t C_2(s)\,ds \tag{11}$$

In the similar way, it follows from (8) and (10) that:

$$C(x,t)|_{x=L} = Ae^{-L} + \int_0^t C_3(s)\,ds \tag{12}$$

Let be $\widehat{C}(x,\sigma)$ a Laplace transformation. Then, for $\widehat{C}(x,\sigma)$ we get the following problem (13)

$$\frac{\partial^2 \widehat{C}(x,\sigma)}{\partial x^2} - \frac{\sigma}{D}\widehat{C}(x,\sigma) = \frac{A}{D}e^{-x}, \tag{13}$$

$$\widehat{C}(x,\sigma) = \frac{1}{\sigma}\widehat{C}_2(\sigma) + \frac{A}{\sigma}, \tag{14}$$

$$\widehat{C}(L,\sigma) = \frac{A}{\sigma} + \frac{1}{T\sigma}\left[\widehat{C}(L,\sigma) - \widehat{a}(P)(L,\sigma)\right] \text{ i.e. } \widehat{C}(L,\sigma) = \frac{TA - \widehat{a}(P)(L,\sigma)}{T\sigma - 1} \tag{15}$$

The general solution of equation (13) is of the form:

$$\widehat{C}(x,\sigma) = e^{\sqrt{\frac{\sigma}{D}}x}\alpha_1(\sigma) + e^{-\sqrt{\frac{\sigma}{D}}x}\alpha_2(\sigma) + \frac{A}{D-\sigma}e^{-x} \tag{16}$$

where $\alpha_1(\sigma)$ and $\alpha_2(\sigma)$ are determined from boundary conditions (14) and (15):

$$\alpha_2(\sigma) = \frac{1}{e^{-\sqrt{\frac{\sigma}{D}}L} - e^{-\sqrt{\frac{\sigma}{D}}L}}\left[e^{\sqrt{\frac{\sigma}{D}}L}\left(\frac{1}{\sigma}\widehat{C}_2(\sigma) + \frac{A}{\sigma} - \frac{A}{D-\sigma}\right) + \right.$$

$$\left. + \frac{TA - \widehat{a}(P)(L,\sigma)}{T\sigma - 1} - \frac{A}{D-\sigma}e^{-L}\right], \tag{17}$$

$$\alpha_1(\sigma) = \frac{1}{\sigma}\widehat{C}_2(\sigma) + \frac{A}{\sigma} - \frac{A}{D-\sigma} - \alpha_2(\sigma). \tag{18}$$

For determining mass transfer between the active and sorbed gas in pores, it is necessary to determine the mass transfer (consumption) on the cross section $x = L$ [3]:

$$q = -D\left.\frac{\partial C(x,t)}{\partial x}\right|_{x=L}.$$

From (16) we get:

$$\left.\frac{\partial \widehat{C}(x,\sigma)}{\partial x}\right|_{x=L} = \sqrt{\frac{\sigma}{D}}\alpha_1(\sigma)\,e^{\sqrt{\frac{\sigma}{D}}L} - \sqrt{\frac{\sigma}{D}}\alpha_2 e^{-\sqrt{\frac{\sigma}{D}}L} - \frac{A}{D-\sigma}e^{-L} \tag{19}$$

where $\alpha_1(\sigma)$ and $\alpha_2(\sigma)$ are determined from (17) and (18).

Then for

$$\widehat{q}(\sigma) = \sqrt{\frac{\sigma}{D}}\alpha_1(\sigma)\,e^{\sqrt{\frac{\sigma}{D}}L} - \sqrt{\frac{\sigma}{D}}\alpha_2 e^{-\sqrt{\frac{\sigma}{D}}L} - \frac{A}{D-\sigma}e^{-L} \tag{20}$$

we get the following expression.

General quantity of the sorbed gas on formation in time will be:

$$f(t) = S(1-m)\,q(t) \tag{21}$$

where S is specific surface of porous medium, m is porosity.

Gas pressure in porous space corresponds to sorptional properties of rocks. After sharp lowering of pressure in the system, the pressure in micropores whose initial value equals P_H, gradually decreases, when it increases in macropores [3]. Proceeding from this fact, we can write gas concenration with coupling coefficient with pressure.

$$\frac{\partial P}{\partial t} - \frac{\partial^2 P}{\partial x^2} = f(t) \tag{22}$$

where $f(t)$ is determined from (21) $P = P(x,t)$.

Using Laplace transform, we get:

$$\sigma \widehat{P}(x,\sigma) - \widehat{P}(x,0) - \frac{\partial^2 \widehat{P}(x,\sigma)}{\partial x^2} = \widehat{f}(t).$$

Since the initial pressure equals zero, therefore $\widehat{P}(x,0) = 0$. So, for determining $\widehat{P}(x,\sigma)$ we get the equation:

$$\frac{\partial^2 \widehat{P}(x,\sigma)}{\partial x^2} - \sigma \widehat{P}(x,t) = S(1-m)\,\widehat{q}(t) \tag{23}$$

where $\widehat{q}(\sigma)$ is determined from (20).

In particular, in the case:

$$\widehat{a}[P(x,t)] = \int_0^t k(t-s)\,P(x,s)\,dS$$

$$\widehat{a}[P(x,t)] = \widehat{k}(t)\,\widehat{P}(x,\sigma). \tag{24}$$

In this case equation (24) is linear and $\widehat{P}(x,\sigma)$ may be determined from this equation.

In the paper, the conducted calculations allow to estimate gas loss volumes arising both at the expense of cross flows of upper interlayers of undergraund reservoirs and in its absorption process in rock grains that coustitute gas saturated formations.

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Received: February 09, 2010 Revised: May 12, 2010