21009

Modeling of gas filtration around horizontal wells in anisotropic hard reaching reservoirs

***M. Lubkov** *(Poltava Gravimetrical Observatory of NAS of Ukraine)*, **O. Zaharchuk** *(National University " Poltava Politechnic of Yuriy Kondratyk"")*

SUMMARY

On the base of combined finite element - difference method, we carried out computer modeling of filtration processes near horizontal producing wells in anisotropic hard reaching gas reservoirs. The modeling results show for effective exploitation of anisotropic hard reaching gas reservoirs, it is necessary to install horizontal production wells in areas with relatively low permeable anisotropy of the reservoir, to avoid places with presence of shear reservoir permeability. At the installation of horizontal wells in anisotropic hard reaching gas reservoirs, the diagonal arrangement relatively axes of reservoir anisotropy is the most effective. It is necessary to carry out an elaborated analysis of the surrounding anisotropy of the gas reservoir in order such horizontally placement of the well in reservoir, which would provide an intensive filtration process around the well. That is, on the one hand there was no blocking of the gas from the side of reduced reservoir permeability, another hand there was no rapid depletion of the reservoir from the side of increased permeability and free access of gas to the well from all possible directions must be provided.

Introduction In our days, there are important problems of increasing efficiency of the hard reaching anisotropic gas reservoirs exploitation (Ter-Sarcisov, 1999), (Yaskin et al., 2018), (Tuna, 2018). These problems mainly connected with intensification of gas filtration processes in heterogeneous anisotropic hard reaching reservoirs and achievements of economically effective ways of such reservoirs exploitation. In this situation, computer methods of anisotropic gas reservoirs modeling are very powerful, because they allow obtaining and analyzing information in vicinity of gas production wells, which is necessary for effective supporting of the gas raw producing. In addition, they allow discovering and evaluation of specific filtration uncertainties, which appear due to limited geologic information outside the wells. Such information we can obtain by comparatively cheap way and use it for optimal installation of production wells in anisotropic heterogeneous hard reaching gas reservoirs. Nowadays, there are many computer methods, which allow resolving of different practical gas reservoirs production modeling problems (Aziz and Settary, 2004), (Chen et al., 2006), (Ertekin et al., 2001). Another hand, in our time there remain some problems, which connected with accuracy and adequacy of anisotropic hard reaching gas reservoirs modeling in real conditions of gas reservoirs exploitation. Especially important are problems of filtration processes intensifying in anisotropic hard reaching reservoirs for effective gas production supporting. Presented in this work, combined finite element-differences method 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. So it allows adequately calculate pressure distribution near horizontal gas production wells in anisotropic hard reaching reservoirs in real exploitation conditions and has some advantages in comparison with another methods.

Mathematical formulation and solving problem

We will consider productive gas reservoirs in which we can neglect by presence of liquid phase. We also suggest that average thickness of productive gas reservoir considerably smaller than its horizontal sizes. At that case, we can use the ordinary formulation of the plane nonstationary anisotropic piezoconductivity Lebenson problem in rectangular axes (X, Y) such as (Lubkov and Zaharchuk, 2020):

$$\frac{\partial P^2}{\partial t} = \frac{1}{c}\left(k_{xx}\frac{\partial^2 P^2}{\partial x^2} + k_{yy}\frac{\partial^2 P^2}{\partial y^2} + 2k_{xy}\frac{\partial P^2}{\partial x}\frac{\partial P^2}{\partial y}\right) + \gamma; \tag{1}$$

$$P(t=0) = P_0; \tag{2}$$

$$k_b gradP^2 = \alpha(P^2 - P_b^2). \tag{3}$$

Here (1) – nonstationary anisotropic piezoconductivity Lebenson equation; (2) – initial condition; (3) – condition of gas infiltration in reservoir's borders; $P(x,y,t)$ – pressure, as function of coordinates and time; $c = \eta m / P_0$ - coefficient of Lebenson piezoresistivity; k_{xx}, k_{yy}, k_{xy} - anisotropic coefficients of gas permeability; η – gas dynamic viscosity; m – porosity of gas reservoir; P_0 – initial pressure of the gas reservoir; P_b – gas pressure in the border of investigating reservoir; k_b – gas boundary permeability; α - coefficient of the gas infiltration in the border of reservoir; γ - power of the gas well production.

For resolving nonstationary anisotropic piezoconductivity Lebenson problem, we use variation finite element method, which leads to the solving of variation Lebenson piezoconductivity equation:

$$\delta \mathrm{I}(P) = 0. \tag{4}$$

Here I(P) – functional of anisotropic piezoconductivity Lebenson problem (1) – (3), which after substitution $\tilde{P} = P^2$ can be presented as functional of usual anisotropic piezoconductivity problem (Lubkov and Zaharchuk, 2020):

$$\mathrm{I}(\tilde{P}) = \frac{1}{2}\iint_S \{k_{xx}(\frac{\partial \tilde{P}}{\partial x})^2 + k_{yy}(\frac{\partial \tilde{P}}{\partial y})^2 + 2k_{xy}\frac{\partial \tilde{P}}{\partial x}\frac{\partial \tilde{P}}{\partial y} + 2\int_{P_0}^{P} c\frac{\partial \tilde{P}}{\partial t}d\tilde{P} - 2\gamma\tilde{P}\}dxdy - \frac{1}{2}\int_L \alpha(\tilde{P} - 2\tilde{P}_b)\tilde{P}dl \tag{5}$$

here S – the square of investigating reservoir; L – contour, which surrounds the square S, dl – element of the contour.

For resolving variation equation (4) we use eight-nodal isoparametric quadrangular finite element (Lubkov and Zaharchuk, 2020). As global coordinate system, where we unit all finite elements of investigating area *S*, rectangular system (X, Y) is using. As local coordinate system, where in limits of every finite element we define approximation functions φᵢ and make numerical integration, normalizing coordinate system (ξ, η) is used. In that system coordinates, pressure, initial pressure, pressure in the border of investigating reservoir, coefficient of gas penetration in the reservoir border and derivatives of pressure on coordinates approximated in such way:

$$x=\sum_{i=1}^{8}x_i\varphi_i;y=\sum_{i=1}^{8}y_i\varphi_i;\tilde{P}=\sum_{i=1}^{8}P_i\varphi_i;\tilde{P}_0=\sum_{i=1}^{8}P_{0i}\varphi_i;\tilde{P}_b=\sum_{i=1}^{8}P_{bi}\varphi_i;\alpha^2=\sum_{i=1}^{8}\alpha_i\varphi_i;$$

$$\frac{\partial\tilde{P}}{\partial x}=\sum_{i=1}^{8}P_i\Psi_i;\frac{\partial\tilde{P}}{\partial y}=\sum_{i=1}^{8}P_i\Phi_i;\Psi_i=\frac{1}{|\mathrm{J}|}(\frac{\partial\varphi_i}{\partial\eta}\frac{\partial y}{\partial\xi}-\frac{\partial\varphi_i}{\partial\xi}\frac{\partial y}{\partial\eta});\Phi_i=\frac{1}{|\mathrm{J}|}(\frac{\partial\varphi_i}{\partial\xi}\frac{\partial x}{\partial\eta}-\frac{\partial\varphi_i}{\partial\eta}\frac{\partial x}{\partial\xi}); \tag{6}$$

here $\mathrm{J}=\frac{\partial y}{\partial\xi}\frac{\partial x}{\partial\eta}-\frac{\partial y}{\partial\eta}\frac{\partial x}{\partial\xi}$ - Jacobian matrix between systems (x, y) and (ξ,η).

Following to variation equation (4) and suggesting, that nodal meanings from derivatives of pressure on time $\frac{dP_i}{dt}$ known values and cannot be variated, we get system of differential equations for k – nodal of p – finite element in such view:

$$\frac{\partial\mathrm{I}_p}{\partial P_k}=\sum_{i=1}^{8}\{\mathrm{H}_{ki}^p\frac{dP_i}{dt}+(A_{ki}^p+\mathrm{Q}_{ki}^p)P_i-\mathrm{Q}_{ki}^p\,P_0^i\}-\gamma_k^p=0; \tag{7}$$

$$\mathrm{H}_{ij}^p=\int_{-1}^{1}\int_{-1}^{1}c^p\varphi_i\varphi_j\,|\mathrm{J}|d\xi d\eta;\mathrm{A}_{ij}^p=\int_{-1}^{1}\int_{-1}^{1}(k_{xx}^p\Psi_i\Psi_j+k_{yy}^p\Phi_i\Phi_j+k_{xy}^p\Psi_i\Phi_j)|\mathrm{J}|d\xi d\eta;\mathrm{Q}_{ij}^p=\int_L\alpha\varphi_i\varphi_j dl;$$

$$\gamma_i^p=\int_{-1}^{1}\int_{-1}^{1}\gamma^p\varphi_i\,|\mathrm{J}|d\xi d\eta.$$

For resolving the system of linear differential equations of the first order (7) at initial conditions (6) we use method of finite differences. At that, approximation of derivative in time we can realize on the base of implicit differential scheme (Aziz and Settary, 2004):

$$\frac{d\tilde{P}}{dt}=\frac{\tilde{P}(t+\Delta t)-\tilde{P}(t)}{\Delta t}. \tag{8}$$

Putting expression (8) into the system (7), we obtain the next system of linear algebraic equations:

$$\sum_{i=1}^{8}\{(\frac{1}{\Delta t}\mathrm{H}_{ki}^p+A_{ki}^p+\mathrm{Q}_{ki}^p)P_i(t+\Delta t)-\frac{1}{\Delta t}\mathrm{H}_{ki}^p\,P_i(t)-\mathrm{Q}_{ki}^p\,P_0^i\}-\gamma_k^p=0\ (k=1-8). \tag{9}$$

After summing equations (9) at all finite elements, we obtain the global system of linear algebraic equations, which allows defining unknown meanings of gas pressure at the moment of time $t+\Delta t$ via their meanings at previous moment t. Further, we resolve the global system equations on the base of Gauss numerical method (Lubkov and Zaharchuk, 2020). After solving the system, we can define pressure in all nods of the finite element net. Therefore, we can determine reservoir gas pressure in any points of investigating reservoir area in any times.

Modeling of gas filtration around horizontal producing wells in anisotropic reservoirs

In modeling, we consider filtration processes around horizontal producing wells in anisotropic hard reaching gas reservoir. Let's suggest that power of producing wells is 24840 m^3 over day at reservoir pressure 10 MPa. With calculation of gas expansion when going out, the gas well power will be $2{,}484\cdot10^6$ m^3 over day. Let us suggest that area of considering gas reservoir is 9×9 km^2. We choose some characteristic parameters of the gas reservoir: k = 0,0012 D(Darsi)= $0{,}12\cdot10^{-14}\,\mathrm{m}^2$; η = $0{,}18\cdot10^{-4}$ Pa·s; m = 0,15; $P_0=1$ MPa, at that coefficient of gas piezoresistivity $c=0{,}27\cdot10^{-12}$ (Basniev et al., 2003). We suggest not gas penetrating processes in the boundaries of the gas reservoir. We have presented obtained results of gas filtration processes modeling in the figures 1 – 3:

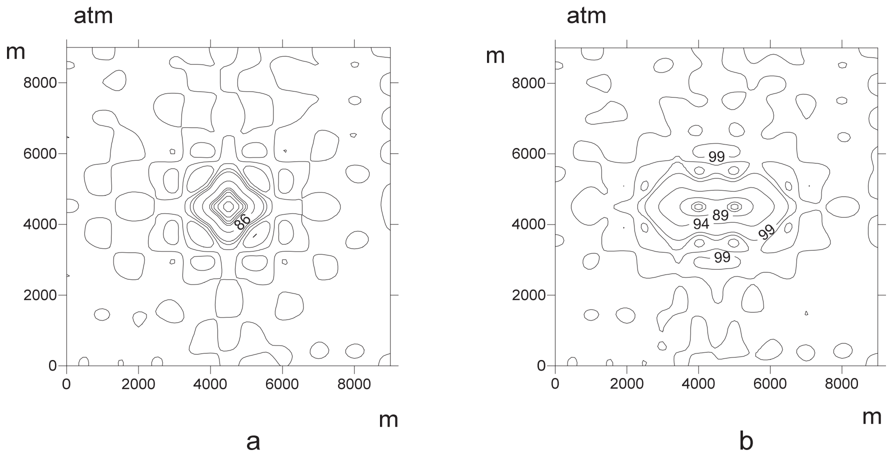


Figure 1. a, b *Distribution of pressure over 30 days in vicinity of the different length horizontal wells(directed along X axe) at permeability of the gas reservoir* $k_{xx} = k_{yy} = k_{xy} = 0{,}0012D$*: a) 1 km; b) 3 km.*

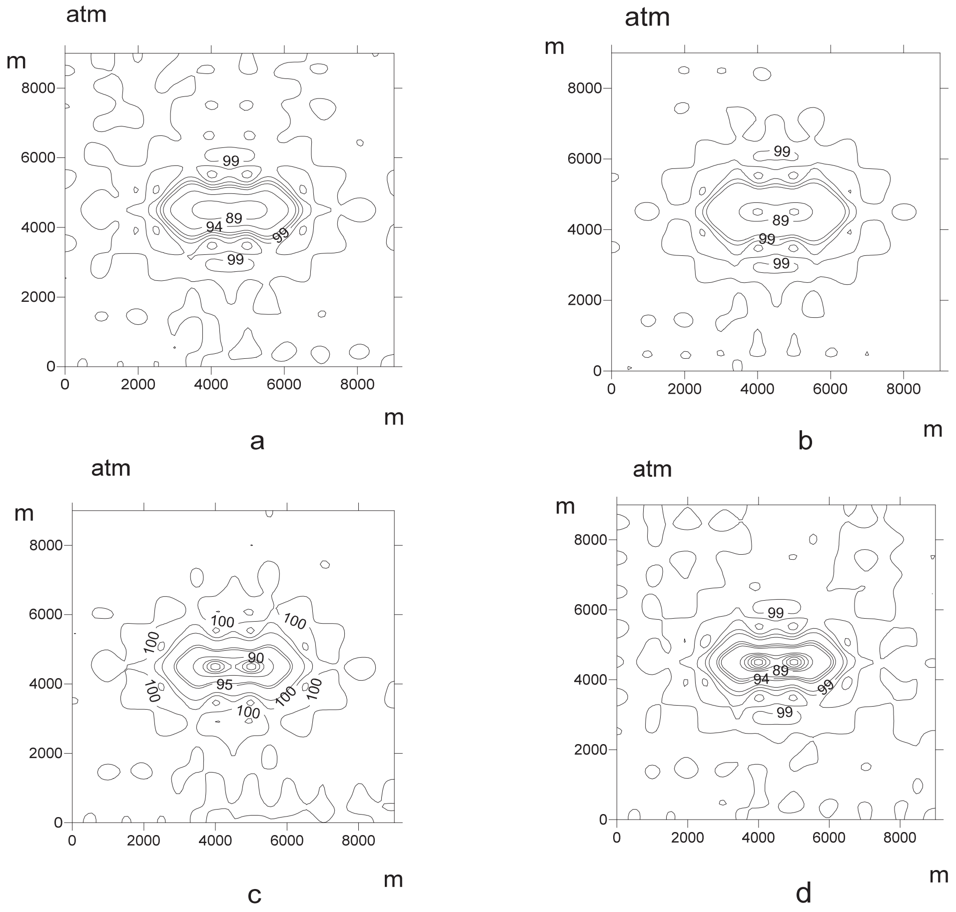
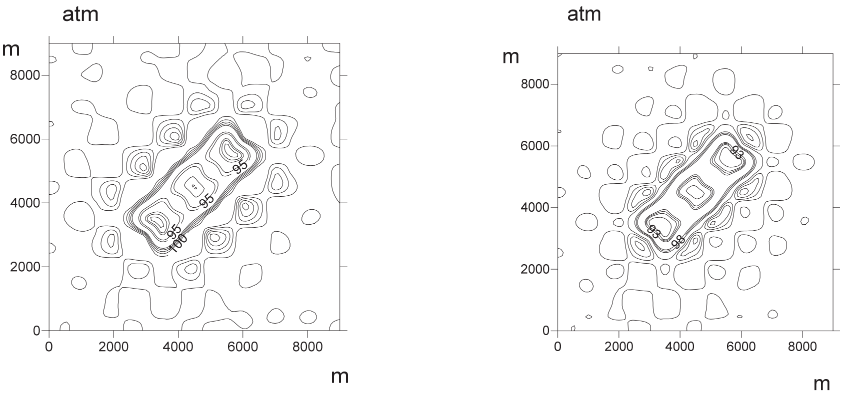


Figure 2. a, b, c, d *Distribution of pressure over 30 days in vicinity of horizontal well with length of 3 km (directed along X axe) at different permeability parameters of the gas reservoir: a)* $k_{xx} = k_{yy} = 0{,}0012D$*,* $k_{xy} = 0$*; b)* $k_{xx} = 0{,}012D$*,* $k_{yy} = k_{xy} = 0{,}0012D$*; c)* $k_{xx} = k_{xy} = 0{,}0012D$*,* $k_{yy} = 0{,}012D$*; d)* $k_{xx} = k_{yy} = 0{,}0012D$*,* $k_{xy} = 0{,}012D$*.*



a b

Figure 3. a, b *Distribution of pressure over 30 days in vicinity of horizontal well with length of 3 km (directed along diagonal direction of anisotropy axes) at different permeability parameters of the gas reservoir: a)* $k_{xx} = k_{yy} = k_{xy} = 0,0012D$*; b)* $k_{xx} = 0,012D$, $k_{yy} = k_{xy} = 0,0012D$.

Conclusions

The elaborated combined finite element - difference method of resolving nonstationary anisotropic piezoconductivity Lebenson problem in heterogeneous gas reservoirs allows adequately in quantitative level to describe the pressure distribution around horizontal gas producing wells in anisotropic hard reaching reservoirs. The modeling results show that intensity of filtration processes around horizontal production well significantly depends on its length and location in the anisotropic gas reservoir. We have come to conclusions, for effective exploitation of anisotropic hard reaching gas reservoirs, it is necessary to install horizontal production wells in areas with relatively low permeable anisotropy of the reservoir, to avoid places with presence of shear reservoir permeability. At the installation of horizontal wells in anisotropic hard reaching gas reservoirs, the diagonal arrangement relatively axes of reservoir anisotropy is the most effective. It is necessary to carry out an elaborate analysis of the surrounding anisotropy of the gas reservoir in order such horizontally placement of the well in reservoir, which would provide an intensive filtration process around the well. That is, on the one hand there was no blocking of the gas from the side of reduced reservoir permeability, another hand there was no rapid depletion of the reservoir from the side of increased permeability and free access of gas to the well from all possible directions must be provided. Therefore, the best results of exploitation in any practical situation can be achieved due to optimal selection of all important factors of horizontal wells placement in anisotropic hard reaching gas reservoirs. Another hand, these factors can be estimated using presented method.

References

Aziz, H., Settary, A. [2004] Mathematic modeling of reservoir systems. Inst. of comput. investigations, Moscow. (in Russian).

Basniev, K.S., Dmitriev, N.M., Rozenberg, G.D. [2003] Oil-gas hydromechanics: textbook for higher education. Inst. of comput. investigations, Moscow. (in Russian).

Chen, Z., Huan, G., Ma, Y. [2006] Computational methods for multiphase flows in porous media. Society for Industrial and Applied Mathematics, Philadelphia.

Ertekin, T., Abou-Kassem, J.H., King, G.R. [2001] Basic applied reservoir simulation. Richardson, Texas.

Lubkov, M.V., Zaharchuk, O.O. [2020] Modeling of filtration processes in heterogeneous anisotropic gas reservoirs. *Geoinformatics (Ukraine),* 1, 56–63. (in Ukrainian).

Ter-Sarcisov, R.M. [1999] Natural gas fields development. Nedra, Moscow. (in Russian).

Tuna, E. [2018] Drilling of horizontal wells in carbonate reservoirs of Middle East for Petroleum Production – investigation of hydraulics for the effect of tool joints. *Hittite journal of Science and Engineering,* 3, 239–247.

Yaskin, S.A., Muhametshin, V.V., Andreev, V.E., Dubinskij, G.S. [2018] Geotechnological screening of reservoir action methods. *Geology, geophysics and development of oil and gas fields,* 2, 49–55. (in Russian).