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BASIS FOR THE MODEL OF PARAMETER PERMEABILITY PREDICTION OF PRODUCTIVE STRATA IN OIL AND GAS DEPOSITS DEVELOPMENT

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Basis for prediction of strata permeability of oil and gas deposits has been presented. The prediction model from the viewpoint of continuum mechanics (the theory of viscosity-elastic body creeping) is justified in terms of estimating deformation gradient, water permeability, piezoconductivity and permeability of hydrocarbon productive strata. To construct the pattern of these parameters the programming complex «Balance-Hydrodynamics» was used. One of the units of this complex allows the construction of predictive permeability patterns to use only the results of well prospecting seismology and hydrodynamic tests. The method was successfully applied at a number of hydrocarbon deposits development in Tomsk region.

Searches for deposits of hydrocarbon raw material (HCRM) are directed on detection of commercial deposits. The analysis of researches data shows that during searches a much greater number of displays of hydrocarbons and nonindustrial deposits occur. From the point of view of geological structure such objects are complex for development. Results of researches (seismic, geophysical, etc.) are difficultly interpreted because they belong to continental or transgenic deposits. These factors considerably complicate the process of deposit mathematical model construction and demand new techniques of analysis and interpretation of the initial geological information. According to the modern requirements to design documentation it is necessary to carry out computer modeling of oil and gas deposits and on the basis of such results to receive design decisions.

Market condition and oil price allow an owner to undertake operation of small deposits opened by one well where, as a rule, the core of the productive layer does not fully characterize its physical properties. At the same time Russian legislation «O nedrach» demands from owner exact observance of design levels of extraction and, hence, owner raises requirements to the project on reliability of their calculations. In the near future a question on insurance of design risks will arise.

Three-dimensional modeling assumes authentic construction of not only deposit HCRM configurations, but also modeling of the layer physical parameters, which are a part of calculation formulas of initial debits, and dynamics of development parameters change for all period of deposit operation. Initial data for construction of three-dimensional model of deposit geometric volume are results of seismic prospecting works, which give adequate representation about geometry of the deposit due to increase in seismic researches and their correlation by results of prospecting wells research using the method of vertical seismic profiling.

Filling of three-dimensional model by physical properties at small testing along the core is not enough for deposit modeling which opening is confirmed by one productive prospecting well and two-three wells which have opened HCRM deposit in the edge zone.

At geological model construction of liquid hydrocarbons deposits at small amount of wells a problem arises about correct construction of permeability and piezo conductivity patterns and, as consequence, patterns of permeability. Geology of oil layer was taken as basis.

The offered model is filtrational, but spatially described filtration-capacitor characteristics of productive layer lie in its basis. Permeability parameter is one of them.

The fixed picture of oil layer geology at the moment of researches is a long process of its formation. Complex processes which took place in bowels of the Earth influenced the process of its formation. As a result of these processes the petroliferous layer has acquired complex geometry due to deformations which have occurred during the long historical period. It allows considering, that research of petroliferous layer (PL) can be conducted from position of the applied creep theory which uses a lot of positions of the plasticity theory and representations of rock destruction mechanics [1–3].

It is obvious that productivity of wells at other equal conditions essentially depends on layer hydraulic conductivity which, in its turn, depends on rock porosity, viscosity of liquid fraction, superfluous internal pressure, etc. Operating experience of petrocrafts shows that in one deposit the wells closely located to each other give frequently essential distinction in productivity [4]. It is possible to explain this feature as wells with the greatest productivity and debit are drilled in places conterminous with places of PL layer destruction, the greatest jointing, shifts which have occurred as a result of their creep, which sharply increases hydraulic conductivity. However, present fields of pressure, which also operate a course of liquid transfer through jointing rocks, influence hydraulic conductivity.

Thus, place prediction of wells drilling for oil with the greatest debit is, as a matter of fact, a search for places of layer rock destruction during creep.

It is known from the theory of creep that condition of the body that was a subject to long process of loading is possible to describe by [3]:

1. differential equations of balance;
2. geometrical equations connecting components of displacement with components of deformation and fair for any continuous body irrespective of its physical nature (Koshi's equation);

3. physical equations (the law of form and volume change);
4. boundary conditions which reflect balance of boundary points at any moment (static); presence of discrete connections on the external border of the body (geometrical); the law of deformation speeds distribution or displacement speeds of the same boundary points of the body (kinematic).

Type of these equations (and sometimes their presence) is defined by the accepted model of body. In the theory of creep few models of body are offered. The strictest is the model of elastic-viscous body and viscous-plastic body.

The theory of creep in this case is interesting with reference to real PL rocks.

Therefore as a first approximation for model of body we shall accept an elastic-viscous body. For such body the specified above equations have the view [3]:

1. $$\frac{\partial \sigma_x}{\partial x}+\frac{\partial \tau_{xy}}{\partial y}+\frac{\partial \tau_{xz}}{\partial z}+X\rho=\rho\frac{\partial^2 u}{\partial t^2},$$

$$\frac{\partial \tau_{yx}}{\partial x}+\frac{\partial \sigma_y}{\partial y}+\frac{\partial \tau_{yz}}{\partial z}+Y\rho=\rho\frac{\partial^2 v}{\partial t^2},$$

$$\frac{\partial \tau_{zx}}{\partial x}+\frac{\partial \tau_{zy}}{\partial y}+\frac{\partial \sigma_z}{\partial z}+Z\rho=\rho\frac{\partial^2 w}{\partial t^2},$$

where X,Y,Z are the projections to corresponding axes x, y, z of volumetric force, u,v,w are the displacements in corresponding directions of axes, σ and τ are the normal and tangent tensions, ρ is the multiplier.

2. $$\varepsilon_x=\frac{\partial u}{\partial x};\quad \varepsilon_y=\frac{\partial v}{\partial y};\quad \varepsilon_z=\frac{\partial w}{\partial z},$$

$$\gamma_{xy}=\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x};\quad \gamma_{yz}=\frac{\partial v}{\partial z}+\frac{\partial w}{\partial y};\quad \gamma_{zx}=\frac{\partial w}{\partial x}+\frac{\partial u}{\partial z},$$

i. e. $\varepsilon_{ik}=\frac{1}{2}\left(\frac{\partial u_i}{\partial x_k}+\frac{\partial u_k}{\partial x_i}\right)$,

where ε_x, ε_y, ε_z are the linear deformations, γ_{xy}, γ_{yz}, γ_{zx} are the angular deformations.

3. $$\sigma_{cp}=E_0\varepsilon_{cp},\quad D_{и}+n\dot{D}_{и}=2GD_{деф}+\frac{2}{3}Hn\,\dot{D}_{деф},\quad (1)$$

where $D_{и}$, $D_{деф}$ are the deviators of tension and deformation; $\dot{D}_{и}$, $\dot{D}_{деф}$, are the deviators of their speeds, n, Hn is the proportionality coefficient of tension and deformation speeds, E is the Young's moduls.

4. Kinematic equations reflecting the law of deformation speeds distribution or speeds of body boundary point displacement are not sited since geometry of the body and its border should be set.

In turn, in development of the viscous-elastic body theory different models have been created and described. So, for Foyg's body dependence of tension and deformations has the view [1]:

$$\sigma=E\varepsilon+\eta\frac{d\varepsilon}{dt},$$

where η is the coefficient.

Integration of this equation gives:

$$\varepsilon=\frac{\sigma}{E}\left[1-\exp\left(-\frac{E}{\eta}t\right)\right],$$

i. e. deformation is described by the exponential law aspiring to magnitude σ/E at $t\to\infty$.

Materials during long loading become old, i. e. change their properties. This change is called heredity. The account of heredity complicates solution of the viscous-elastic body problem but by means of Laplas' transformations through function image, using Walter's principle, it is possible to find the function σ_{ij} and u_{ij}.

These equations and approaches for finding the solution of intense-deformed condition are cited to show, first of all, that the model of body should be correctly chosen. Secondly, the quantitative estimation of tension is rather inconvenient and in any case is approximate because of assumption acceptance.

Therefore tosolve the problem on search of the destruction zone, fracture of the petroliferous layer it is necessary to take the displacement trajectory of its separate points as contour bases. As a matter of fact, displacements u and v (flat body) are known. Using Koshi's equations we define deformations ε_x and ε_y. The equations (1) allow drawing a conclusion that destruction influences not only the size of deformation, but also a gradient of deformations $\dot{\varepsilon}_x$, $\dot{\varepsilon}_y$, where

$$\dot{\varepsilon}_x=\frac{\partial^2 u}{\partial x^2};\quad \dot{\varepsilon}_y=\frac{\partial^2 v}{\partial y^2}.$$

Operating tensions in the massif also have an influence on hydraulic conductivity. This influence is essential; it can increase or decrease hydraulic conductivity. Deformations dominate for two-dimensional case in jointing environment increasing directed hydraulic conductivity [5]:

$$\begin{cases} K_x=\dfrac{g}{12\mu s}(b+\Delta b_y)^3 \\ K_y=\dfrac{g}{12\mu s}(b+\Delta b_x)^3 \end{cases},$$

where K_x and K_y is the directed hydraulic conductivity; g is acceleration of free falling, μ is the kinetic viscosity, s is the side of allocated unit of the area without cracks and pores, b is the total linear size of pores and cracks, Δb_x and Δb_y is the change of size b in directions x and y.

Displacement tensions influence hydraulic conductivity essentially, thus Δb_x and Δb_y are defined as:

$$\begin{cases} \Delta b_x=\Delta b_{xn}+\Delta b_{xs} \\ \Delta b_y=\Delta b_{yn}+\Delta b_{ys} \end{cases}, \quad (2)$$

where Δb_{xn}; Δb_{xs} and Δb_{yn}; Δb_{ys} are the displacements in x and y directions from normal and displacement tensions.

Directed hydraulic conductivity depending on linear and displacement deformations in view of dependence (2) is defined as:

$$\begin{cases} K_x=\dfrac{g}{12\mu s}\{b+[b+s(1-R_e)]\Delta\varepsilon_y+(s+b)(1-R_g)\left|\Delta\gamma_{xy}\right|\}^3 \\ K_y=\dfrac{g}{12\mu s}\{b+[b+s(1-R_e)]\Delta\varepsilon_x+(s+b)(1-R_g)\left|\Delta\gamma_{xy}\right|\}^3 \end{cases}.$$

If hydraulic conductivity in initial conditions

$$K_0 = \frac{gb^3}{12\mu s},$$

then the general dependence between hydraulic conductivity and deformation has the view:

$$\frac{K_{ii}}{K_0} = \left\{ 1 + \left[1 + \frac{s(1-R_e)}{b} \right] \Delta\varepsilon_{jj} + (1+\frac{s}{b})(1-R_g)\left|\Delta\gamma_{ij}\right| \right\}^3,$$

where $K_{ii}(i=x,y)$ is the hydraulic conductivity in direction x, y; $\Delta\varepsilon_{jj}(j=x,y)$ and $\Delta\gamma_{ij}(i,j=x,y)$ are the induced deformations; R_e, R_g are the parameters characteristic for the given rock, and $R_g=G/G_\gamma$, $R_e=E/E_\gamma$, where G_γ, G and E_γ, E are the displacement modules of the intact and given massif and normal modules respectively.

After conducted calculations of deformation gradient ($\Delta\varepsilon$), hydraulic conductivity (K), piezo conductivity (χ) we have 3 vectors:

$$\Delta\varepsilon_1,\Delta\varepsilon_2,...,\Delta\varepsilon_i;\ K_1,K_2,...,K_i;\ \chi_1,\chi_2,...,\chi_i,$$

where i is the number of wells.

It is necessary to define functions of dependences:

$$\ln K_i = f_1(\ln\Delta\varepsilon_i), \quad (3)$$

$$\ln\chi_i = f_2(\ln K_i), \quad (4)$$

to what the regression analysis is applied. Considering physics of the process, functions should be monotonous and, hence, it is possible to accept linear regress and regress of the exponential type.

In case of linear regression $y=b_0+b_1x$ the method of the least squares is applied, and the estimation is calculated by factors of correlation, determination, F-criterion and by a standard estimation error (equation).

In case of exponential type of regression $y=c+\exp(b_0+b_1x)$ where instead of x and y values $\ln\Delta\varepsilon_i$, $\ln K_i$ and $\ln c\chi_i$ are inserted for dependences (3) and (4) respectively, the Quasi-Newton method is used which allows calculating function values in various points for the first and the second derivative estimation. It is always possible to estimate full dispersion of the dependent variable (full sum of squares), share of dispersion as the remainder (sum of squares of mistakes), and share of dispersion regarding the regression model (sum of squares regarding regress) regardless of the considered model.

Thus, having geology of oil layer the isofield of deformation gradient can be constructed. Then, using the above-stated dependences the patterns of piezo- and hydraulic conductivity can be constructed. It is possible to specify drilling places of the most effective on debit wells based on these dependences. Such approach has been applied at development of more than thirty HCRM deposits of Tomsk area and Western Siberia.

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