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О МОДЕЛИРОВАНИИ ВОДОХРАНИЛИЩ В УСЛОВИЯХ ВОДОПРИВОДНОГО РЕЖИМА

ABOUT RESERVOIR MODELING UNDER WATER DRIVE MODE CONDITIONS

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Аннотация. Моделирование пластов в нефтедобыче является стандартной операцией для решения проблем разработки пластов [1]. Технология моделирования пластов постоянно совершенствуется, предлагаются новые модели для более сложных процессов разработки. Это искусство сочетания физики, математики, технологии добычи нефти и компьютерных программ для разработки моделей, позволяющих прогнозировать поведение углеводородных коллекторов и определять способы повышения конечной нефтеотдачи при различных эксплуатационных стратегиях [2].

Ключевые слова: моделирование, дебит, давление, геометрический фактор, сетка, метод IMPES.

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Annotation. Reservoir modeling in oil production is the standard operation for solving problems in the development of reservoirs. [1]. Reservoir modeling technology is constantly being improved, new models are being offered for more complex development processes. It is the art of combining physics, mathematics, oil production technology, and computer programs to develop models to predict the behavior of hydrocarbon reservoirs and determine how to enhance the ultimate oil recovery in various operational strategies [2].

Keywords: *modelling, production rate, pressure, geometrical factor, grid, IMPES method.*

Conventional reservoir development forecasting methods can be divided into three categories: by analogy, experimental and mathematical methods.

Methods by analogy are used in predicting the development of oil deposits that have similar geological characteristics.

Experimental methods are applied to determine the physical characteristics (e.g. flow rate, pressure or saturation) from a laboratory model and the results of the studies refer to the entire oil reservoir.

Finally, mathematical methods use equations to predict reservoir development [3].

Reservoir modeling is usually performed in several stages:

1. It is necessary to establish the objectives of the study. The first step in a successful simulation study is the understanding of clear and achievable goals that are consistent with the available field data, as well as to define the main modeling strategy, identify the resources available to do so, and determine the outcome of the study.
2. Get and check all the data of the formation. After the objectives of the study have been determined, field information is collected on the dynamics of oil, liquid, etc. Only the data necessary to build the model is needed, because including unnecessary additional details leads to a distorted model.
3. Build a reservoir model. After all the necessary data is collected and verified, then the model is built. In this step, the reservoir under study is divided into grid blocks, and reservoir properties such as porosity, permeability, and pay thickness are plotted on these grid cells. Grid cells can have different reservoir properties, but within a grid cell, the reservoir properties are assumed to be uniform. Since different cells may have different properties, areal and vertical trends in the data can be included in the model. At this stage of the study, all study data is scaled for mesh simulation.
4. Adaptation of the reservoir model. Once a model is built, it must be validated to the actual field development data available, as much of the data in a typical model is unknown, but for some it is the result of engineering interpretation. While these interpretations are usually better than the available data, they are subjective and subject to change.
5. Forecasting. The last step in the modeling process is the forecasting stage, which evaluates, analyzes and predicts various parameters and development systems [3, 4].

The field and its model differ for the following reasons:

1. The input data is questionable. Measurements of any kind are subject to error. For example, the determination of permeability by the core impregnation method gives a series of values centered around an average. Deciding which of the available measurements are sufficient to calculate the average permeability and which of them reflect the real permeability is the main task. One of the main most time-consuming parts of modeling is the collection of all kinds of data and the assessment of their reliability. This often takes much more time than the direct creation of a hydrodynamic model. If the input data is presented with sufficient accuracy, then the model predicts the development of the reservoir well and behaves in the same way as the field, although there may not be a superficial similarity between the model and the field conditions.
2. Geological-physical, capacitive and filtration characteristics of the deposit may be unknown. Well data provides information about the drainage zone and general information about the characteristics of the field at some distance from this zone. Seismic data provide additional information about the structure. All other geological information is either assumed or extrapolated
3. Fluid simulation may not be suitable for modeling some processes. All hydrodynamic models are discrete numerical models approaching a continuous system. The diffusion equation on which the simulation is based is a non-linear partial differential equation that can only be directly solved by the program for very simple models. Instead, an approximation in the form of linear differential equations is solved. For example, differential equations are not applicable to highly compressible fluids, so they cannot describe in detail the movement of free gas at sufficiently high pressures, typically starting at about 3500 psia. This is typical of well inflow from the grid cells they are associated with, in which case a choice of equation for inflow calculation is provided.
4. The hydrodynamic model introduces certain formulations that modify the performance of the model. All hydrodynamic modeling programs represent a field and wells as a set of points capable of producing, receiving, and containing fluids. These points represent large and complex objects, and the method by which field properties are averaged to create properties at individual points defines the extent to which the model's performance changes. For example, one cell of the hydrodynamic simulation grid can be at a depth of 3 km, have one porosity value, three *X*, *Y*, and *Z* permeability values, net-to-gross values, and a set of relative permeability and capillary pressure curves. These cells are perceived by the program as points. In simulation, the fluid will flow through the grid cells in the same way as through the rock, if all of the above properties are averaged and/or coarsened so that all flow characteristics are preserved. To do this, there is a procedure known as upscaling and its essence is to eliminate errors due to the discretization of the field.

Although modeling is the most comprehensive method for predicting the condition of oil reservoirs, it will not replace the classical engineering approach to reservoir development. A well-conducted simulation study will always use the results of study materials from several classical methods. For example, in the reservoir characterization phase of the simulation study, pressure build-up analysis is the preferred method for obtaining permeability. During development, the material balance method can be used to obtain information on water cut and aquifer size.

In an oil-water system, it can be assumed that there are two liquid components as well as two phases. Oil and water are considered immiscible components, so there is no mass transfer between the oil and water phases. In addition, it is assumed that the flow is isothermal and the phases are in a state of thermodynamic equilibrium.

The flow equation for an oil-water system using the IMPES (implicit pressure-explicit saturation) method in its final form is

$$\begin{gathered}\sum\nolimits_{m\in\psi_n}\left(\beta_{o_n}^{n+1}T_{o_{n,m}}^{n}+\beta_{w_n}^{n+1}T_{w_{n,m}}^{n}\right)p_{o_m}^{n+1}-\left[\left(\beta_{o_n}^{n+1}C_{op_n}+\beta_{w_n}^{n+1}C_{wp_n}\right)+\sum\nolimits_{m\in\psi_n}\left(\beta_{o_n}^{n+1}T_{o_{n,m}}^{n}+\beta_{w_n}^{n+1}T_{w_{n,m}}^{n}\right)\right]p_{o_m}^{n+1}=\\ =-\left[\left(\beta_{o_n}^{n+1}C_{op_n}+\beta_{w_n}^{n+1}C_{wp_n}\right)p_{o_n}^{n}\right]-\left(\beta_{o_n}^{n+1}q_{osc_n}^{n}+\beta_{w_n}^{n+1}q_{wsc_n}^{n}\right)+\\ +\sum\nolimits_{m\in\psi_n}\beta_{w_n}^{n+1}T_{w_{n,m}}^{n}\Delta_m P_{cow}^{n}+\sum\nolimits_{m\in\psi_n}\left(\beta_{o_n}^{n+1}T_{o_{n,m}}^{n}\overline{\gamma}_{o_{n,m}}^{n}+\beta_{w_n}^{n+1}T_{w_{n,m}}^{n}\overline{\gamma}_{w_{n,m}}^{n}\right)\Delta_m z\end{gathered}\tag{1}$$

Phase saturation equation:

$$S_o+S_w=1,\tag{2}$$

where S_o – oil saturation, fractions of units; S_w – water saturation, fractions of units; P_{cow} – capillary pressure in the oil-water system, psi; $T_{o_{n,m}}^{n}$ – oil conductivity, STB/D.psi; $T_{w_{n,m}}^{n}$ – water conductivity, STB/D.psi, and capillary pressure:

$$P_{cow}\left(S_w\right)=p_o-p_w=f\left(S_w\right),\tag{3}$$

$$S_{w_n}^{n+1}=S_{w_n}^{n+1}+\frac{1}{C_{ww_n}}\left\{\sum\nolimits_{m\in\psi_n}\left[T_{w_{n,m}}^{n}\left(\Delta_m P_o^{n+1}-\Delta_m P_{cow}^{n}-\overline{\gamma}_{w_{n,m}}^{n}\Delta_m z\right)\right]-C_{wp_n}\left(p_{o_n}^{n+1}-p_{o_n}^{n}\right)+q_{wsc_n}^{n}\right\},\tag{4}$$

$$T^n_{w_{n,m}} = G_{n,m}\left(\frac{1}{\mu_w\beta_w}\right)^n_{n,m}\left(k_{rw}\right)^n_{n,m}, \tag{5}$$

$$T^n_{o_{n,m}} = G_{n,m}\left(\frac{1}{\mu_o\beta_o}\right)^n_{n,m}\left(k_{ro}\right)^n_{n,m}, \tag{6}$$

$$G_{n,m} = \beta_c\frac{k_x A_x}{\Delta x}, \tag{7}$$

where k_{ro} – relative permeability for oil, fractions of units; k_{rw} – relative permeability for water, fractions of units; μ_o – oil viscosity, cp; μ_w – water viscosity, cp; β_o – oil volume factor, bbl/STB; β_w – water volume factor, bbl/STB; G – geometrical factor; k_x – permeability in *X*-direction, md; A_x – block cross-sectional area in the *X*-direction, ft^2

Geometric factors, G for an anisotropic porous medium and for irregular rectangular distribution grid blocks are given in Table 1 [3].

Table 1 – Geometric Factors in Rectangular Grid

Direction	Geometrical factor
X	$G_{x_{i\pm1/2,j,k}} = \dfrac{2\beta_c}{\Delta x_{i,j,k}/\left(A_{x_{i,j,k}}k_{x_{i,j,k}}\right)+\Delta x_{i\pm1,j,k}/\left(A_{x_{i\pm1,j,k}}k_{x_{i\pm1,j,k}}\right)}$
Y	$G_{y_{i,j\pm1/2,k}} = \dfrac{2\beta_c}{\Delta y_{i,j,k}/\left(A_{y_{i,j,k}}k_{y_{i,j,k}}\right)+\Delta y_{i,j\pm1,k}/\left(A_{y_{i,j\pm1,k}}k_{y_{i,j\pm1,k}}\right)}$
Z	$G_{y_{i,j,k\pm1/2}} = \dfrac{2\beta_c}{\Delta z_{i,j,k}/\left(A_{z_{i,j,k}}k_{z_{i,j,k}}\right)+\Delta z_{i,j,k\pm1}/\left(A_{z_{i,j,k\pm1}}k_{z_{i,j,k\pm1}}\right)}$

Checking the material balance in multi-phase flows is carried out for each component in the system. Each component, oil and water is contained in system, therefore:

$$I_{MB} = \frac{\sum\limits_{n=1}^{N}\frac{V_b}{a_c\Delta t}\left[\left(\frac{\varphi S_p}{\beta_p}\right)^{n+1}_n-\left(\frac{\varphi S_p}{\beta_p}\right)^n_n\right]}{\sum\limits_{n=1}^{N}\left[q^{n+1}_{pscn}+\sum_{l\in v}q^{n+1}_{pscl,n}\right]}. \tag{8}$$

Conclusion

The general equation of multi-dimensional single-phase filtration is given. A model of motion in the oil-water system is presented, all of the above boundary conditions are considered. To solve the model equation, the IMPES solution method can be used to obtain linear flow equations.

The system of linear equations for all blocks can be solved using any solution method (for example, the Thomas algorithm) to obtain a solution for one-time step.

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