Methods of adjusting geophysical parameters in the calculation of numerical simulation of an oil and gas reservoir to obtain reliable simulation results

TOAN Phan Trong*

PVEP PetroVietnam Exploration Production Corporation, Branch in Ho Chi Minh city, Vietnam

Abstract. The method of numerical simulation is widely used today to manage the flow obtained from an oil/gas reservoir. However, the geophysical data provided for the simulation program is unreliable, so the numerical simulation results in large errors compared to reality. The paper presents some methods for correcting geophysical data in numerical simulation to obtain reliable simulation results.

Introduction

Natural gas and oil are gathered from reservoir by production wells. The assessment of oil and gas reserves in reservoirs, the forecast of production flow and management of reservoir resources and others often uses the Digital Simulation Technology (DST) widely. However, the results of DST are difficult to match the actual reservoir conditions.

The change in pressure in the reservoir gives us a picture of the moving of oil and gas in the reservoir, so that most of the digital simulation problem will calculate the pressure distribution in the reservoir in a time period of any. Pressure at any position in the reservoir can be calculated from the digital simulation, while the pressure measurement at that position is not possible. Therefore, numerical simulation results always need more measurement data to standardize. In fact, it is only possible to measure pressure in the reservoir at some locations with wells. Therefore, the measurement data is not sufficient to standardize digital simulation results.

This article presents some experience to accurately determine of geophysical parameters while solving the digital simulation problem to increase conformity actual of digital simulation results.

Reservoir pressure field determination by numerical simulation

The structure of petroleum reservoir consists of several layers overlapping dimensional oz. The thickness of each layer is very small comparing to the length and width of the layer.

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*Author email: toanpt@pvep.com.vn

On the other hand, vertical permeability in the reservoir is very small comparing to the other directions. Therefore, studying a petroleum reservoir can only study any layer representing the reservoir. A three-dimensional problem of multi-layer research can be transferred to a two-dimensional problem of studying a class. In order to present the experience of adjusting the geophysical parameters of the oil and gas reservoir, without losing the generality of the digital simulation method, this article investigates the digital solution to solve a two-dimensional boundary problem of finding pressure distribution in a natural gas reservoir, one-layer structure, thickness h. The reservoir is divided into block grid. Each element of the grid (cell) is a rectangular box with dimensions like in figure 1. Block grid elements (called grid cells) are numbered and have a defined position according to the row index i (along the ox direction) and column index j (along the oy direction) as Figure 2.

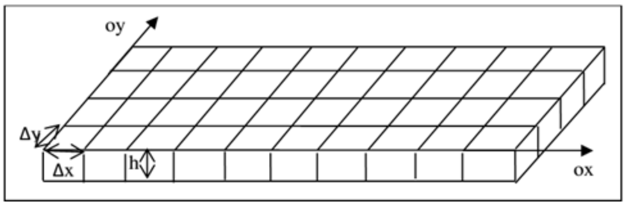

Figure 1. Image of a block grid. Each block of the grid has dimensions Δx , Δy and h

	j =1	2	3	4	5	6	7	
i=1	1	2	3	4	5	6	7	
2	8	9	10	11	12	13	14	
3	1	16	17	18	19	20	21	
4	2	23	24	**25**	26	27	28	
5	2	30	31	32	33	34	35	
6	3	37	38	39	40	41	42	
7	4	44	45	46	47	48	49	

Figure 2. 2-dimensional reservoir presented by ox and oy directions. Dark cells form the outer boundary of the reservoir. Cells are numbered for their position in the reservoir. Location of cell 25 is arranged with production well, which is inter boundary of the reservoir

For example, a two-dimensional boundary problem applies to the gas reservoir as follows:

two-dimensional partial differential equation with pressure unknown p (pressure equation) describes pressure changes in the reservoir:

$$\frac{\partial^2 p}{\partial x^2} + \frac{\partial^2 p}{\partial y^2} = \frac{\emptyset \mu c}{0.006328k} \frac{\partial p}{\partial t} \tag{1}$$

conditions of outer boundary:

$$\left.\frac{\partial p}{\partial x}\right|_{\Gamma x} = \left.\frac{\partial p}{\partial y}\right|_{\Gamma y} = 0; \quad p|_{\Gamma} = p_{init} \tag{2}$$

conditions of inner boundary (at well position):

$$p_w = const < p_{init} \tag{3}$$

initial conditions: t=0 at the time of the original reservoir, there were no production wells; t = t_0 at any time, the reservoir is in production.

$$p\big|_{t=0} = p_{init} \tag{4}$$

or,

$$p\big|_{t=t_0} = p_{(x,y)} \tag{5}$$

Geophysical parameters in the porous environment of the reservoir related to pressure are as follow:

$$\phi = \phi(p) \tag{6}$$

$$\mu = \mu(p) \tag{7}$$

$$\kappa = \kappa(p) \tag{8}$$

$$c = c(p) \tag{9}$$

Here: p_{init}, $p_{(x,\ y)}$, p_w, k, h are respectively the initial pressure, pressure in any position, well pressure (internal boundary pressure), permeability and height of gas reservoir; c is the compression coefficient of the gas, μ - viscosity of the liquid and ϕ - porosity, respectively.

At the initial state of reservoir at t = 0, geophysical parameters in each grid cell are determined by upscalling technology [1,2]. With DST, these data are combined with the finite difference method [3,4] to find the solution of the boundary problem. The solution (P) of the boundary problem is a set of pressure values p defined at the center of each grid cell at any time t.

Partial differential equation (1) is converted into corresponding finite difference system of equations and apply to all positions of grid-cell. The solution (P) is obtained from solving the following system of algebraic equations:

$$|A|\vec{x} = |B| \tag{10}$$

$$\vec{x} = \frac{|B|}{|A|} \tag{11}$$

Here $|A|$ and $|B|$ are coefficient matrices. $|A|$ is square matrix in diagonal form. $|B|$ is the column matrix. The components of the vector $\vec{x}$ is the unknown pressure at the center of each grid-cell.

In the next step we divide time t into small enough time intervals Δt and $t = n\Delta t; n = 1,2,3\ldots N.$ To determine the pressure field (P) at time t, we must calculate N set of pressure field $(P)_n$ with n = 1,2,3 ... N. The steps to calculate are as follows:

The first step in n = 1:

In the initial state t = 0, reservoir pressure everywhere has the same value, equal to the initial pressure of the reservoir.

Using geophysical parameters in the initial pressure state of each grid cell we calculate components of $|A|$ and $|B|$ corresponding to p_{init} pressure state.

We solve equation (11) to find $(P)_1$ at the time of time $t_1 = n\Delta t = \Delta t$

Step to calculate pressure in time t_2, n = 2:

We calculate geophysical parameters in the pressure state $(P)_1$ for each grid-cell according to the expressions (6-9).

Next, we calculate the components of $|A|$ and $|B|$ according to known data at the pressure state $(P)_1$.

We solve equation (11) to find $(P)_2$ at the time $t_2 = n\Delta t = 2\Delta t$

Continue to the last calculation step in n = N:

We calculate geophysical parameters in the pressure state $(P)_{N-1}$ for each grid-cell according to the expressions (6-9).

We calculate the components of $|A|$ and $|B|$ according to known data at the pressure state $(P)_{N-1}$.

We solve (11) to find $(P)_N$ at the time $t = t_N = n\Delta t = N\Delta t$.

Methods to adjust geophysical parameters

The geophysical parameters of each grid-cell in the initial state t = 0 are generated from the upscaling technology. In these data set there is lack of measuring results to standardize, so they are not accurate data. Therefore, the results of the digital simutation problem are difficult to match the actual conditions of the reservoir. To overcome this, geophysical parameters at each grid cell should be standardized according to the actual conditions of the reservoir. Here, there are some experiences.

On the basis of set of actual measurement data of geophysical parameters at different locations of the reservoir, we can find expressions (6-9). From these expressions, we determine the value of geophysical parameters when knowing the pressure p in any position (i, j) of the reservoir. If p is correct, it will be calculated the exact geophysical values, and vice versa. Correct adjustment of geophysical parameters is equivalent to adjustment of pressure p at different locations in the reservoir. Expressions (6-9) are always re-standardized whenever new measurements are added.

DST allows determining the pressure field $(P)_n$ at each step of calculation n. The set of pressure values of $(P)_n$ is determined exactly with reservoir conditions, which will be used to adjust the geophysical parameters in grid cell locations at the next calculation steps.

In the step of calculating n any corresponding time period Δt , the solution $(P)_n$ is determined by solving the system of equations (11). Repeat s times for solving the equation (11) in step n, then the results obtained $(P)_{ns}$ are not the same. When s is large enough, $(P)_{ns}$ changes little. It is necessary to select a sufficiently small change of $(P)_{ns}$ for step n. Therefore, it is important to note that when determining a solution $(P)_{ns}$, a sufficient level of accuracy is required at each time step Δt .

When solving the system of equations (11) at the time step n = 1 with the initial condition (4). At time t = 0, assume that the pressure at the center of the grid-cells is equal and equal to the pressure p_{init} of the reservoir. However, boundary conditions (5) can be applied instead of (4). It means using any pressure value instead of p_{init} or choosing any set of pressure values (P) for the initial pressure state of the reservoir. Mathematically, after doing s times the system of equations iteration (11) we always determine an exact solution at the necessary level for this system of equations. However, pressure values according to boundary conditions (5) are usually assumed pressure. They are not measured values in the initial state corresponding to the position of each grid cell. Therefore, geophysical parameters calculated by expressions (6-9) will not be accurate for each grid-cell in that initial state. Thus, the determination of the coefficient matrices $|A|$ and $|B|$ in the system of equations (11) will be different from the case of determining them when using the condition (4). So, it should be noted that when solving the system of equations (11), it is not only mathematically accurate but also accurate in terms of physical meaning and timing.

Solving the system of equations (11), using the initial condition (4) will be favorable because the reservoir pressure is the same everywhere. The value of geophysical parameters is changed over time from the same initial time point t = 0. However, simulation for reservoir status with long time will take a long time to calculate. If using the initial condition (5), there will be two difficulties in practice. One is that it is impossible to measure simultaneous pressure at all grid locations. The second is the very small number of grid positions that can measure pressure. However, the simulation program uses initial conditions (5) for much less computational time. Below, there is the Hypothetical Simulation Method which presents the experience to transform the initial condition (4) to (5) and vice versa. This helps the simulation program to be applied in practice even when using the initial conditions (4) or (5).

Description of Hypothetical Simulation Method

Solve the system of equations (11) using the initial condition (5) with pressure $p_{(x, y)}$ in different positions but it is unclear at what time, called hypothetical simulations. Pressure difference $dp = p_{init}-p_{(x, y)}$ or $p_{(x, y)} = p_{init}-dp$ at each position of grid-cell with coordinates (x, y) is determined. Hypothetical simulations also determine the period of time $n\Delta t$ at which the pressure $p_{(x, y)}$ at any position (i, j) changes a dp value. So, we can convert the initial condition (4) to (5) using the expression $p_{init} = p_{(x, y)} + dp$ and vice versa, convert (5) to (4) using the expression $p_{(x, y)} = p_{init}-dp$.

In fact there are very few pressure values measured from the reservoir due to the limited number of wells. Therefore, it is always necessary to add new pressure measurement values to the digital simulation program to standardize geophysical parameters. However, these parameters can be standardized by the digital simulation program by the method below.

Description of the method

p_{init} is the measured pressure. Suppose the initial condition (4a) is generated from the initial condition (4) by setting the p_{test} pressure in any grid position (i, j). If $(P)_n$ is the solution of the boundary problem using the initial condition (4) at time step n and $(Pa)_n$ is the solution of the boundary problem using the initial condition (4a) at time step n, then the solution $(P)_n$ and $(Pa)_n$ differ only in adjacent positions (i, j). Thus through DST, these adjacent positions have been adjusted pressure to suit the p_{test} pressure. In general, the solution of the boundary problem at the area near reservoir positions where reliable pressure, will be adjusted in the direction of actual fit of the reservoir. Therefore, it is possible to use the pressure of the cells near the well as the initial condition to adjust the pressure of the cells far from the production well for suitable actual conditions of reservoir.

Conclusion

Digital simulation technology is now widely used in oil and gas industry. Finding out the methods to make digital simulation results well suited to the actual conditions of reservoir is always difficult problem. There are many different methods to solve this problem. The paper presented some methods as good experiences to adjust geophysical parameters to suit actual conditions of reservoir.

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Opiekun : Jadwiga Jarzyna
Recenzent : Jadwiga Jarzyna
Drugi recenzent z Wietnamu