Modification of Permeability Cube of Geologic and Hydrodynamic Model Under Various Volumes of Input Data

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Abstract. At any stage of field development, the process of developing and history-matching geologic and hydrodynamic models has many uncertainties. To improve reliability of geologic and hydrodynamic models all the available information shall be used. For undeveloped fields, these are the results of hydrodynamic well tests at the stage of early production, and for fields with a high degree of exploration all the available information shall be objectively integrated. This paper considers various approaches to improvement of geological and hydrodynamic models’ reliability. The authors propose a method of hydrodynamic model history-matching to indicator diagrams results. To refine permeability cube at underexplored fields, it is proposed to history-match the geologic and hydrodynamic model to the results of hydrodynamic tests carried out at exploration stage. For fields with a high degree of exploration, it is proposed to integrate different studies. Linear discriminant analysis was used for this purpose. As a result, this allowed to significantly reduce the model adaptation time and increase its predictive reliability.

1. Introduction

Existing approaches to oil and gas reservoir engineering always include a stage of reservoir geologic and hydrodynamic modelling [1]. Many uncertainties arise at all stages of reservoir geologic and hydrodynamic modelling. A number of parameters are set with an error that results from insufficient initial data and inaccuracy of methods of reservoir’s porosity, permeability and saturation determination [2]. The degree of uncertainty is particularly high at modelling of fields or individual facilities that have not yet been put into operation. Normally, no well spacing pattern has been formed, and only a couple of exploration or prospecting and appraisal wells have been drilled at such fields. The results of studies of various deposit parameters are limited, often taken from comparable facilities or from closely located fields.

In mature fields, the input data quality, which is usually poor, contributes to errors and uncertainties in the structure, including limited well log surveys, poor-quality tests, no seismic data, insufficiency of development control data, lack of standard hydrodynamic research measurements, and ambiguous data on production and injection rates, particularly in multi-horizon fields with commingled production [3-4].

Where there is a sufficient volume of standard studies of core, reservoir fluids, deposit energy characteristics, seismic data, etc., the issues with objective data integration and their factoring in the process of geologic and hydrodynamic modelling are detected [5].
Absolute permeability is one of the key parameters determining fluid flow pattern in geologic and hydrodynamic modelling. This paper considers approaches to improving reliability of absolute permeability cube development in geologic and hydrodynamic modelling.

2. Materials and methods
For undeveloped fields, absolute permeability, displacement efficiency, well production rates and other parameters are often validated based on comparable facilities. There are data on hydrodynamic well testing for many facilities that have passed early production stage. The use of well test results and their re-interpretation for permeability adjustment at fields with long development history has a high degree of convergence of actual and calculated indicators and allows for better variability in permeability parameter adjustment in the model, complementing the standard approach to the use of petrophysical function [6-7]. As for the fields that have not been put into operation, in the situation of limited amount of data, the use of hydrodynamic test results from exploration wells will allow to determine permeability in the well area most accurately.

The authors propose a technique of reservoir flow simulation model history-matching to the results of indicator diagrams. The technique has been implemented as illustrated by the case of the Savarskoye oil field.

To reproduce the productive reservoir properties and reliably estimate permeability adopted in geologic and hydrodynamic simulation, it was decided to perform history-matching according to steady and non-steady flow tests.

Simulation was conducted using Tempest MORE 8.3.1 software (a Roxar product). For simulation purposes, the hydrodynamic tests performed were entered into the model as historical ones for well history-matching.

In the first stage, the original absolute permeability cube from the geologic model was modified by multivariate calculations using a multiplier to the original petrophysical function to reproduce fluid withdrawals during the test. Permeability was then adjusted to reproduce hydrodynamic well tests. The well multiplier shall equally meet the following three requirements:

1) The absolute permeability average of oil-saturated part in the reservoir flow simulation model does not diverge from that accepted in geological and physical characteristics in a certain range;

2) The absolute permeability average shall be close to the data obtained in the actual pressure buildup curve, equal to 449 mD in the well-drainage area;

3) Matching the history of well operation parameters with different chokes (correct productivity).

In the reservoir simulation model, permeability by wells can be modified by varying the radius of interpolation. In case of a rather dense well-spacing pattern, the radius of interpolation shall be taken as equal to half of the distance between wells, i.e. as per relative well-drainage radius.

At undeveloped fields with a small number of drilled wells, the hydrodynamic research data shall be factored in for correct interpolation.

As there are different methods to estimate drainage area and drainage radius, the authors [8] estimated drainage radius having processed pressure buildup data and compared it with the Chekaliuk’s technique. In this paper, the drainage radius was calculated using the latter technique for express estimation, the received value equalling to 321 m.

The resulting actual and simulated well operation is shown in Figure 1.
Figure 1. Well operation parameters during exploration phase.

Figure 2 shows a comparison of the taken indicator diagram. The actual and synthetic indicator diagrams are approximated by straight-line equations, since the bottom-hole pressure values exceeded the bubble point [9, 10]. No inertial components, connection of additional productive thickness, reservoir deformation or other factors were detected. Final permeability in oil-saturated part of reservoir equals to 400 mD and meets all necessary requirements.

Figure 2. Comparison of indicator diagrams.

The bottom-hole pressure deviations between the actual and synthetic (simulated) indicator diagrams do not exceed 2.8 %, which confirms high convergence in the reservoir flow simulation model.

Let us consider the opposite case - a field that has been put into operation, with a formed spacing of production drilling and a large number of standard and special field studies, the Vostochno-Lambeysorskoye field.

The substantial volume of initial data available including well log surveys results, standard and special core tests, hydrodynamic surveys, seismic surveys, etc., poses the need for their integrated accounting in geologic and hydrodynamic modelling.

Interwell space features the greatest uncertainty in modelling, which can misrepresent fluid flow, especially for complex reservoirs. The standard approach to distribution of permeability parameter in interwell space consists in setting a petrophysical function of porosity distributed over deposit volume using various geostatistical interpolation methods. The existing approach already at the initial stage
introduces a significant error in the distribution of permeability values, as the permeability-porosity relationship is averaged and does not factor in the spread of values. Figure 3 shows that porosity values of 10% correspond to permeability values in the range between 2.8 and 3.215 mD.

While the use of petrophysical function is justified for formations with low anisotropy of properties, for the geologic and hydrodynamic modelling of complex reservoirs that requires to factor in heterogeneity of porosity and permeability, presence of secondary processes, influence of faults, and stress-strain behaviour, a more detailed and scientifically validated approach to permeability parameter distribution shall be taken.

The use of seismic attributes is proposed in [11-15] to improve the accuracy of reservoir properties distribution in interwell space. To improve the history-matching quality, it is proposed to integrate all field data before the history match [16].

Using the case of the complex carbonate formation of the Vostochno-Lambeyshorskoye field, an analysis of core studies was carried out. It is proposed to use linear discriminant analysis to factor in interference of permeability, porosity, density, calcite, dolomite and insoluble residue content. A refined permeability cube was then developed, history-matching to hydrodynamic studies was performed and hydrodynamic model calculations were conducted using the created cube.

The results of porosity, permeability and rock composition determination on 333 standard and full-diameter core samples were analysed.

Presumably, dolomitization is the main process affecting available rock capacity of the formation [17].

Linear discriminant analysis was carried out to factor in the influence of secondary processes on reservoir permeability buildup. The analysis was aimed at identifying a set of indicators affecting the rock permeability the field under study.

In the course of the analysis, all the samples were classified into two groups by absolute permeability (class 1: $K_{\text{perm}} < 50$ mD; class 2: $K_{\text{perm}} > 50$ mD). The parameters of porosity, density, calcite, dolomite and insoluble residue content were used in the calculations.

Obtained was a linear discriminant function (Z) dividing the groups by permeability index.

$$Z = 0.184 \cdot K_p + 0.009 \cdot D\% - 3.06 \cdot 9d + 6.327$$

$K_p$ – porosity factor, $D\%$ - dolomite content, $9d$ - rock density.

$R$ (multiple correlation coefficient) = 0.78.

The percentage of classification accuracy is 100% for class 1 and 80% for class 2, which attests to reliability of the resulting classification model. The physical validity of the model can be defined by the coefficients on the indicators. Thus, for porosity and dolomite content the coefficients have a positive sign, i.e. the higher their values, the higher the permeability. For density, the lower the value,
the higher the permeability. Further, the transition to probabilistic estimation of absolute permeability values ($P(Z)$) was made.

$$P(Z) = 0.013\cdot Z^4 - 0.067\cdot Z^3 - 0.0145\cdot Z^2 + 0.47\cdot Z + 0.451 \quad (2)$$

Given the probability value, a transition to the predictive estimate of the permeability value in the deposit volume is possible.

3. Results
Given the probabilistic model built, the following approach to refining the absolute permeability cube in geologic and hydrodynamic modelling is proposed. In the first step, using porosity, density, calcite and dolomite rock content curves calibrated from core data, property cubes are created by interpolating the parameters throughout the model. Depending on parameters values, a $Z$ criterion cube is built using linear discriminant function equation. In the next step, depending on criterion $Z$, a transition to the cube of probability of referring permeability to values greater or less than 50 mD is made. Subject to probability values, a cube of refined absolute permeability is built. Thus, the main advantage of this approach in the permeability cube development consists in integrated accounting of parameters effect on permeability values, which allows for a more reliable and scientifically validated distribution of permeability values in interwell space.

4. Conclusion
In the course hereof, two different approaches have been proposed to improve the predictive reliability of geologic and hydrodynamic models. The case of limited amount of initial data has been considered. To refine permeability cube for such fields, it is proposed to adjust geologic and hydrodynamic modelling to the results of hydrodynamic surveys carried out at the exploration stage. Reservoir absolute permeability adjusted in this way in the flow simulation model, is the most validated, and well productivity is adjusted correctly.

For a field with a high degree of exploration, it is proposed to integrate a set of studies. Linear discriminant analysis was used for an integrated accounting of various parameters and their influence on permeability. As a result, this allowed to significantly reduce the history-matching time and increase its predictive reliability.

The adjustment of absolute permeability is of strategic importance in geologic and hydrodynamic modelling as it has a dominant impact on the production plateau in deposit engineering and energy characteristic.

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