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Clastic Reservoirs Productivity Index Estimation with Well Log Data

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Abstract

Fluid filtration and mass transfer processes description are the key issue of the geological modeling and oilfields development design for reservoirs with complex structure. The well log data interpretation results are the basis of reservoir characterization.

The advanced application of the effective porosity value provides description of reservoir properties for dynamic (absolute, effective and relative permeabilities, capillary pressures, free fluids) reservoir simulation. The outcome values of effective porosity and clay swelling index are properties, which confidently reflect filtration reservoir parameters.

It is stated that effective porosity determined with log data provides evaluation of relative/phase permeability values and hydrocarbon distribution in transition zones using capillary pressure models. The application of Buckley Leverett function for known effective permeability gives evaluation of oil share in production. It is established that effective porosity has strong correlation with productivity index for wide range of clastic reservoir rocks from different region. Thus, the determination of effective porosity from well logs is resulted in prediction of oil and water amounts in production.

The effective porosity determination with log data is complex task, which could be solved with NMR log or conventional log data interpretation. Authors of stated work developed petrophysical models and appropriate algorithms (adaptive log data interpretation) for effective porosity determination based on adaptation to well logging tools metrology and reservoir conditions. These algorithms provide determination of effective porosity values with conventional well logs (spontaneous potential log, formation density log, gamma-ray log, neutron log and sonic log). Proposed models of capillary pressure and relative/phase permeabilities are used in dynamic reservoir properties prediction algorithms. Dynamic properties are transferred in digital geological and hydrodynamic models for reservoir development process simulation.

The well log derived effective porosity is used for reservoir rocks productivity index prediction. Oil and water effective/relative permeabilities have close relation to effective and dynamic porosity and this fact provides determination of oil and water effective/relative permeabilities in reservoirs as well as oil and water amounts in production. Obtained results are applied for fluid filtration processes modeling and reservoir development technology design.

Introduction

Pure oil could be produced in the best case at the start of oilfields development with water flooding. Then some water starts to show up. This water volume tends to increase over time due to water injection and the two-phase flow of fluids begins to predominate in the oil reservoir.

The displacement of oil with water is controlled by relative permeability functions for oil and water, and by the ratio of fluids viscosities. Functions of relative permeability also determine the dynamics of water influx in the tranzition zones.

The relative permeability functions can be effectively used to predict the initial water flow rate, when initial saturation has not been changed by reservoir development. Brooks-Corey model [1] is widely used to generalize the core data.

Not only the probable water cut, but its volume (daily rate) must be known for the prediction of oil production from the wells coming on stream.

The classical way to solve this problem is the application of the Dupuis formula, which is Darcy equation solution for stationary radial flow of formation fluids to the well. In evaluating of the well performance, it is more convenient to operate with a formation productivity index, which is independent from the value of depression.

The conclusion about the adequacy of the forecast to the real geological objects can be made by comparing the actual and predicted production.

Implementation of such techniques can significantly reduce the prediction error of water production flow rates for new wells and increase the operational reliability of production forecasts.

In this paper a method of productivity index and the initial water influx estimation is proposed. This technique takes into account effective porosity, relative permeabilities, as well as well logging data.

Productivity Index Evaluation from Well Logging Data

There are two most common ways to forecast production rates: theoretical and statistical. For the implementation of the first way the information about the parameters of the formation (the effective and relative permeabilities, reservoir thickness, drainage radius), well (skin factor or reduced range radius, the quality factor of penetration, etc.) and the properties of the saturating fluid (volume ratios, viscosity) is needed. Based on the expected flow rate Q, the productivity index K_{prod} and specific productivity index η are calculated.

Statistical method for predicting is realized by constructing the correlations obtained by using the well test results (Q, K_{prod}, η) and petrophysical parameters tuning according to well logging data.

Hereafter the technique of specific productivity index calculating is proposed. It's based on statistical correlation between the value of effective porosity and specific productivity, separated for each production target. The assumption of the stated dependences presence is based on the tightness of the correlations between the effective porosity and permeability [6].

A close correlation between specific productivities and effective porosity averaged on reservoir thickness for Cretaceous reservoirs BU_{10} and BU_{14} from one oilfield of Western Siberia is shown on Fig. 1a and 1b. This dependence is described with the equation:

$$\eta = \alpha \phi_{ef}^{\beta}, \quad (1)$$

where α and β are empirical constants for each individual production target.

Studied reservoirs are represented with quartz-feldspathic sandstones with intergranular structure of the capacitive space.

Effective porosity is determined with the adaptive interpretation (described in [5]) of the standard well log data.

Data from 50 wells were used to obtain stated correlation. Presented deviation of particular points are concerned, in particular, with some differences in the penetration conditions and reservoir thickness used for averaging.

Production flow rate per well from specific productivity index could be calculated using given pressure gradient and net pay value.

The obtained productivities can be used for operational forecast of initial production rates of new wells. It's needed to be clarified according to the hydrodynamic modeling. Nevertheless, this information does not reflect the actual content of flows.

Prediction of Reservoir Performance in the Inter-Well Space

The initial water cut of oil wells is controlled with relative permeability functions for oil and water. M.Masket is first to establish a fact later confirmed by the number of researchers: relative permeabilities are functions of water saturation [2-4].

The most of attempts to model relative permeability is based on the Purcell equation [4], which includes capillary pressure and relative permeability, wherein the pore space is modeled by a set of capillaries with certain radius. N.T.Burdine proposed relative permeability models taking into account saturation changes as functions of the capillary pressures and free fluids [2].

Authors of [6] developed relative permeability models, operating with phase permeabilities for oil and water, as well as current and effective residual oil saturation (the proportion of oil in the volume of effective porosity). The control parameters of these models have a close correlation with the reservoir characteristics, which allows the calculation of relative permeability functions according to log data.

The relation of control parameters with effective (φ_{ef}) and dynamic (φ_{dyn}) porosity is stated for the studied field set according to the processing of the core data. The resulting regression is as follows: $\kappa = C_1+C_2\varphi_{ef}+C_3\varphi_{dyn}$.

The effective permeability of oil and water is determined with the value of absolute permeability, which is predicted from well log data. Current oil saturation is calculated in two ways to improve the results accuracy in thin beds and heterogeneous productive reservoirs. It is evaluated with resistivity logging (Archie equation and adaptive well log interpretation) and capillary pressure model of transition zone (CPM) [6]. The calculation results with resistivity log are consistent with the CPM.

Relative permeability functions (rel. perm. map for oil is shown on Fig. 2a), predicted on each depth step of well logs are transformed to the water share in flow with Buckley-Leverett equation [6].

To predict the productivity and the initial water cut it is performed geological modeling of the studied deposit. A three-dimensional distribution of the effective porosity, saturation and relative permeability are conducted with described approach. Reservoir performance is predicted from these maps. Map with productivity index is shown on Fig. 2b.

Way to test the three-dimensional distribution of the productivity index is comparison of this parameter with the results of well testing and production logging (MDT data). The comparisons carried out on 20 wells from different parts of the deposit, which did not participate in generation of the correlation on Fig. 1 and 3D modeling of the petrophysical characteristics. Ten monitoring wells include MDT data, the remaining have results interval standardized well tests. In almost all cases, the data from the control wells are close to the prediction of both the oil (Fig. 3a) and the water (Fig. 3b).

Maps of the productivity index and initial water cut resulting from geological modeling are used in the well placement process (Fig. 2b) to reduce water production and increase oil production rates (5 producers are already drilled: 200-300 m^3/day of oil with low water cut 5-15%; recommendations for drilling include 25 new wells).

Results and Conclusions

The technology of production rates and the initial water cut forecast in the inter-well space with interpretation of well logging data has developed for Cretaceous reservoirs of the oilfields in Western Siberia.

Control of the forecast results carried out with comparison of the calculated and actual (according to MDT and selective flow test of well) oil and water flow rates of 20 monitoring wells.

Relative permeability functions are calculed in each cell of the geological model, which gives the necessary physical basis for reservoir simulation process. The result is the adequacy of the geological model to the real reservoir target.

Reference

1. Brooks, R.H., Corey, A.T. Properties of porous media affecting fluid flow // Journal of the Irrigation and Drainage Division, proc of ASCE, 92, № IR2, 1966.
2. Burdine, N.T. Relative Permeability Calculations from Pore Size Distribution Data // Trans. AIME, № 71, 1953.
3. Kjosavik, A., Ringen, J.K. and Skjaeveland, S.M. Relative Permeability Correlation for Mixed-Wet Reservoirs // Paper SPE 59314 presented at the 2000 SPE/DOE Improved Oil Recovery Symposium held in Tulsa, OK, 2000.
4. Purcell, W.R. Capillary Pressures-Their Measurement Using Mercury and the Calculation of Permeability // Trans. AIME, 186, 39, 1949.
5. Kozhevnikov, D.A., Kovalenko, K.V. and Deshenenkov, I.S. Informational Advantages and Accuracy Characteristics of the Adaptive Well Log Data Interpretation // Paper SPE-148676 presented at the 2011 SPE Arctic and Extreme Environments Conference in Moscow, Russia, 2011.
6. Kozhevnikov, D.A., Kovalenko, K.V. and Deshenenkov, I.S. Relative Permeabilities Evaluation with Well Log Derived Effective Porosity // Paper EarthDoc-16371 presented at the 75th EAGE Conference & Exhibition incorporating SPE EUROPEC, London, UK, 2013.

Figures

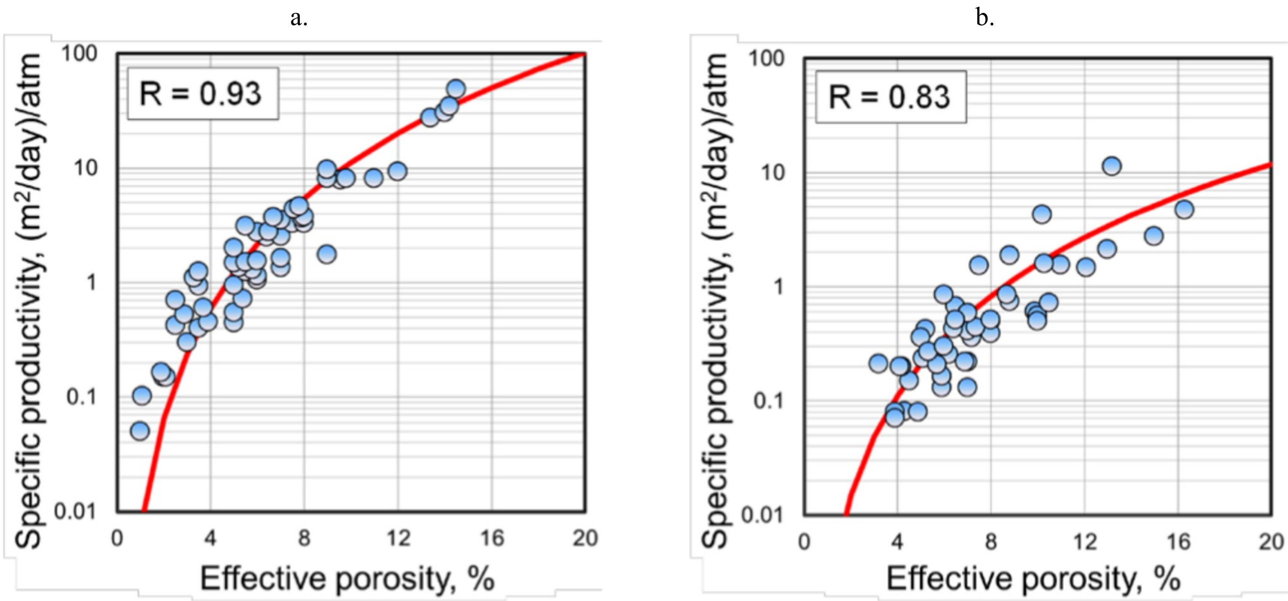

Fig. 1. Comparisons of specific productivity and effective porosity for 50 wells from studied formations BU_{10} (a) and BU_{14} (b) (equation (1))

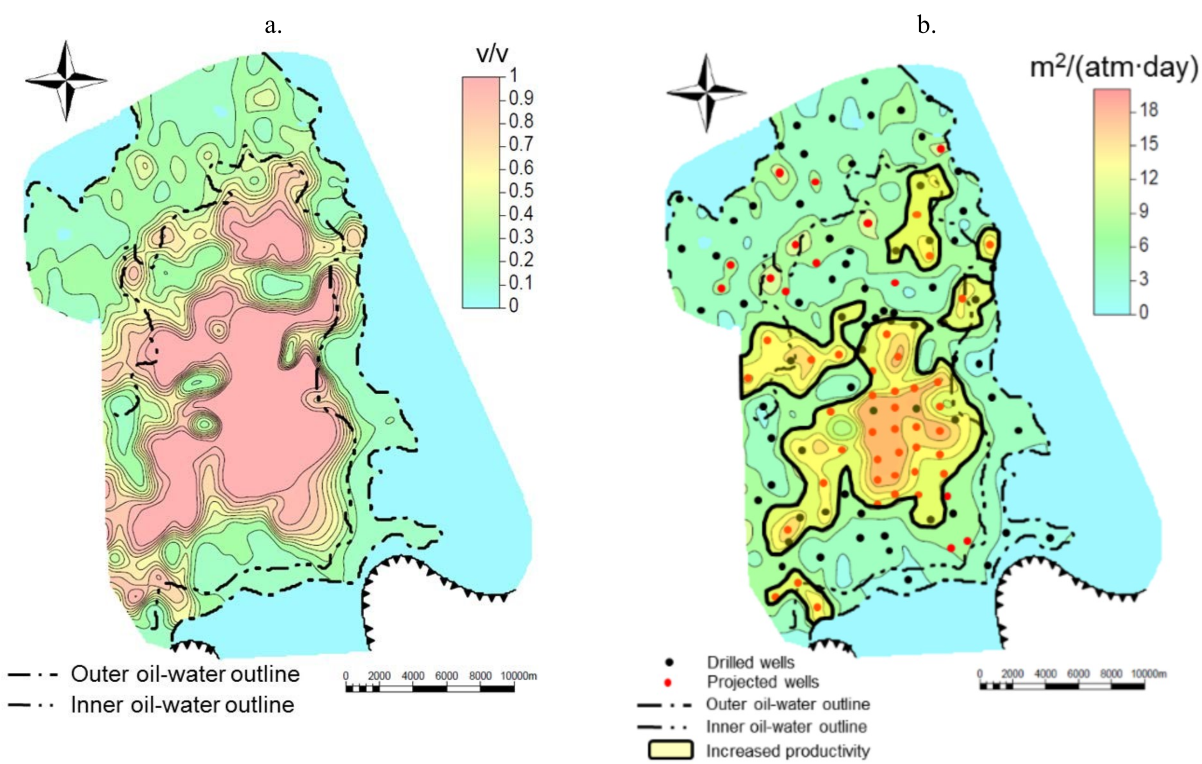

Fig. 2. Maps of a. oil relative permeability and b. specific reservoir productivity for BU_{10} formation.

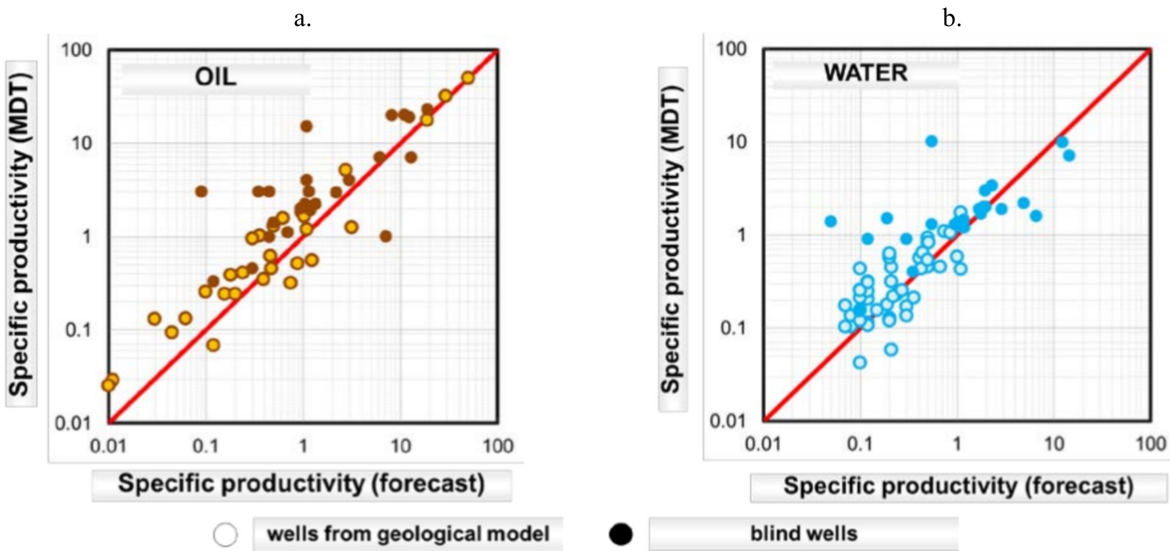

Fig. 3. A comparison of the actual and predicted specific productivity for oil (a) and water cut (b) of the BU_{10} formation.