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COMPLEX PETROPHYSICAL CORRECTION IN THE ADAPTATION OF GEOLOGICAL HYDRODYNAMIC MODELS (on the example of Visean pool of Gondyrev oil field)

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The authors review a method of combined porosity and volume density correction in the process of modeling the distribution of reservoir permeability. Basing on petrophysical investigations of core samples from Bashkir fold deposits, an association between rock porosity, density and permeability has been analyzed. Significant correlation has been observed for the above mentioned parameters in porous collectors in contrast to reduced correlation for dense rocks and intervals of anomalously high poroperm characteristics. For terrigene porous collectors the authors propose a model of permeability assessment based on combined porosity and density correction.

A modified model was developed for Visean pool of Gondyrev oil field, where collector permeability had been calculated as a function of rock porosity and density. The modified model has been compared to the conventional one; significant differences have been detected. In the modified version maximum permeability is associated with the southern part of the pool, whereas the conventional method points out the central part and predicts lowering permeability closer to the periphery. Geological model in the modified version is more homogenous than the conventional one and has no sharp peaks and valleys.

The calculations have been made that reproduce the history of field development for both permeability volumes. Authors demonstrate that total oil production obtained using the modified model has a much better correlation with the actual data. The best results from using suggested method apply to the initial stage of development due to better convergence of high-rate wells.

On the whole, comparison of two methods shows that for the purposes of production history adaptation the modified model is significantly better than the conventional one. Hence, the method of density correction allows for better justification of differences in the lithology of Visean collectors, which ultimately results in higher accuracy of data on residual oil reserves in the deposit.

Key words: core samples, porosity, density, permeability, multiple regression, 3D hydrodynamic model, porous collector, adaptation, well, oil production

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Introduction. The purpose of this work is to improve existing method of hydrodynamic modeling for oil fields. Research focuses on Visean production facilities of the Bashkir fold (Perm Krai). The practice of constructing geological hydrodynamic models shows that one of the key moments defining their accuracy and adaptation quality is objective assessment of permeability coefficient k. When reproducing the history of field development in 3D models, it is the permeability parameter that is subject to the most significant modifications. At the same time, according to current operating procedure [9], it is the contractors who choose the methods of permeability modeling.

In field conditions there are two main approaches to the assessment of permeability coefficient. The first one is based on data from hydrodynamic well tests (HWT). HWT methods allow to obtain a permeability estimate derived from the actual yield of the well. An example of their application in the region of current research is described in the study [7]. However, not the whole area of the pool is characterized by standard k values – this is especially true for production facilities with small well inventories due to insufficient HWT data and its arguable accuracy [5]. Besides, this method implies that the production (perforation) interval is characterized by a single k value without any differentiation in the permeability of separate sublayers. As a result, geological hydrodynamic models that do not take into account core sample data are always vertically homogenous.

An alternative to the HWT approach is the application of petrophysical functions of the porosity coefficient: $k = f(K_p)$. In the process of creating a 3D model of reservoir permeability, the geological foundation of the oil field is based on data from geophysical well tests (GWT). Such geological models better reflect vertical heterogeneity of the section, but are significantly weaker when it comes to horizontal inhomogeneity. This occurs because areas without core sampling have almost no effect on the resulting dependency. It should be noted that Perm Krai deposits are characterized by low rates of core sampling [6], which weakens the correlation between K_p and k.

The method of permeability assessment based on core sampling data with combined porosity and volume density correction. Visean sediments in the investigated region are characterized by a high degree of industrial development and have a long history of field exploitation; in the Bashkir fold they are mostly represented by medium- and fine-grained sandstones, less frequently siltstones [3]. The boundary reservoir properties, below which the rock is considered to be impermeable for fluids, lie in the intervals of $K_p = 11 \div 13$ %, $k = (17 \div 35)10^{-3}$ μm^2. Poroperm characteristics of the rocks in this case vary quite significantly. Aggregation, analysis and classification of accumulated laboratory data for Visean facilities of the Bashkir fold were carried out in order to identify key factors that determine the quality of permeability modeling in the interwell space, which is a critically important issue for the development of 3D models of the oil fields.

In the current study 4167 laboratory samples of rock porosity and permeability have been analyzed. Fig.1, *a* shows that the correlation field between K_p and k has greater dispersion, explained by the fact that the statistical sample has been composed from various-type collectors. Most studies [1, 2, 4, 12] recognize the necessity to take into account rock lithotypes as a defining factor that increases the accuracy of k estimations based on core sampling. According to the authors, a significant improvement of the model accuracy can be achieved by means of obtaining additional petrophysical information beside the core sampling material. With this in mind, volume density of the rock ρ has been analyzed to provide additional description of the voids. Petrophysical data on Visean terrigene collectors has been aggregated into one statistical sample, and correlation fields have been plotted (Fig.1).

Dependency between K_p and k is non-linear, with parameter values scattered along the entire variation interval. One can highlight distinctly different areas of $K_p < 10$ %, where k does not go above its initial values, and $K_p > 10$ %, where k varies in a large interval. The same happens to k in the intervals $\rho > 2.6$ g/cm^3 and $\rho < 2.6$ g/cm^3. In the study [10] it is proposed to divide the rocks into three classes according to the intervals of their petrophysical characteristics and correlation between them: dense rocks (poroperm characteristics below the boundary); porous collectors; super collectors (intervals with anomalously high poroperm characteristics). Significant correlation between petrophysical characteristics, including linear dependency between ρ and K_p, apply only to porous collectors.

In order to justify fluctuation of permeability in the reservoir, this paper reviews the opportunity to develop a model of permeability prediction based on laboratory data with regard to combined influence of rock porosity and density. Multiple regression has been used to assess the impact of several parameters on k values [11, 13]. As a result, multidimensional equations of regression have been obtained for each class mentioned above:

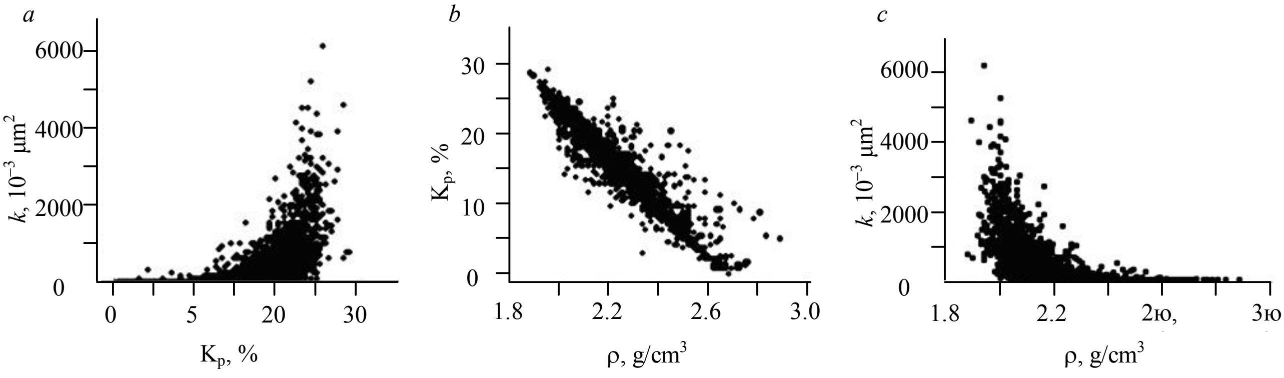

Fig.1. Correlation fields between parameters of Visean terrigene collectors of the Bashkir fold

– dense rocks: $k = 13.9 + 4.3\ K_p - 9.34\ \rho$ at $R = 0.29$;
– porous collectors: $k = -493.4 + 48.9\ K_p - 42.2\ \rho$ at $R = 0.69$;
– super collectors: $k = 1350.2 + 38.6\ K_p - 52.2\ \rho$ at $R = 0.12$.

These multidimensional equations have been obtained for a significantly large area of coeval Visean rocks of the Bashkir fold in the Perm Krai. One can notice that stable relations between k and other multidimensional parameters (at high R values) have been established only for porous collectors. It should be noted that accurate prediction of reservoir permeability is especially relevant for this class of collectors, whereas permeability assessment in non-collectors has no practical implication whatsoever, since they cannot contain any movable oil. The share of wells in super collectors, according to data in the study [8], does not exceed 3 %.

Accuracy of the proposed approach, which takes into account ρ and K_p when estimating k, has been tested in Visean facility wells of Gonyrev oil field. Results of development history adaptation for two methods have been compared. In the first scenario, volume permeability has been modeled using the conventional method based on GWT and the dependency $\ln(k) = 0.712\ K_p - 9.2516$. In the second one, volume permeability has been calculated with a regard to regression equation for porous collectors (modified method).

Analysis of Fig. 2 and 3 demonstrates that the modified method returns much lower volatility of k values throughout the reservoir volume. According to the conventional method, k values often exceed the threshold of $1000\cdot10^{-3}\ \mu m^2$, whereas in the modified scenario the majority of values lie in the interval $(400\text{-}550)10^{-3}\ \mu m^2$. Unlike the conventional model, the modified one is much more homogeneous and has no sharp peaks and values. It should be noted that, according to the modified method, maximum permeability is associated with the southern part of the pool (see Fig.2, *b*). The conventional method links maximum permeability to the central part (up to $2300\cdot10^{-3}\ \mu m^2$) and predicts lowering permeability ($k < 300\cdot10^{-3}\ \mu m^2$) closer to the periphery (Fig.2, *a*).

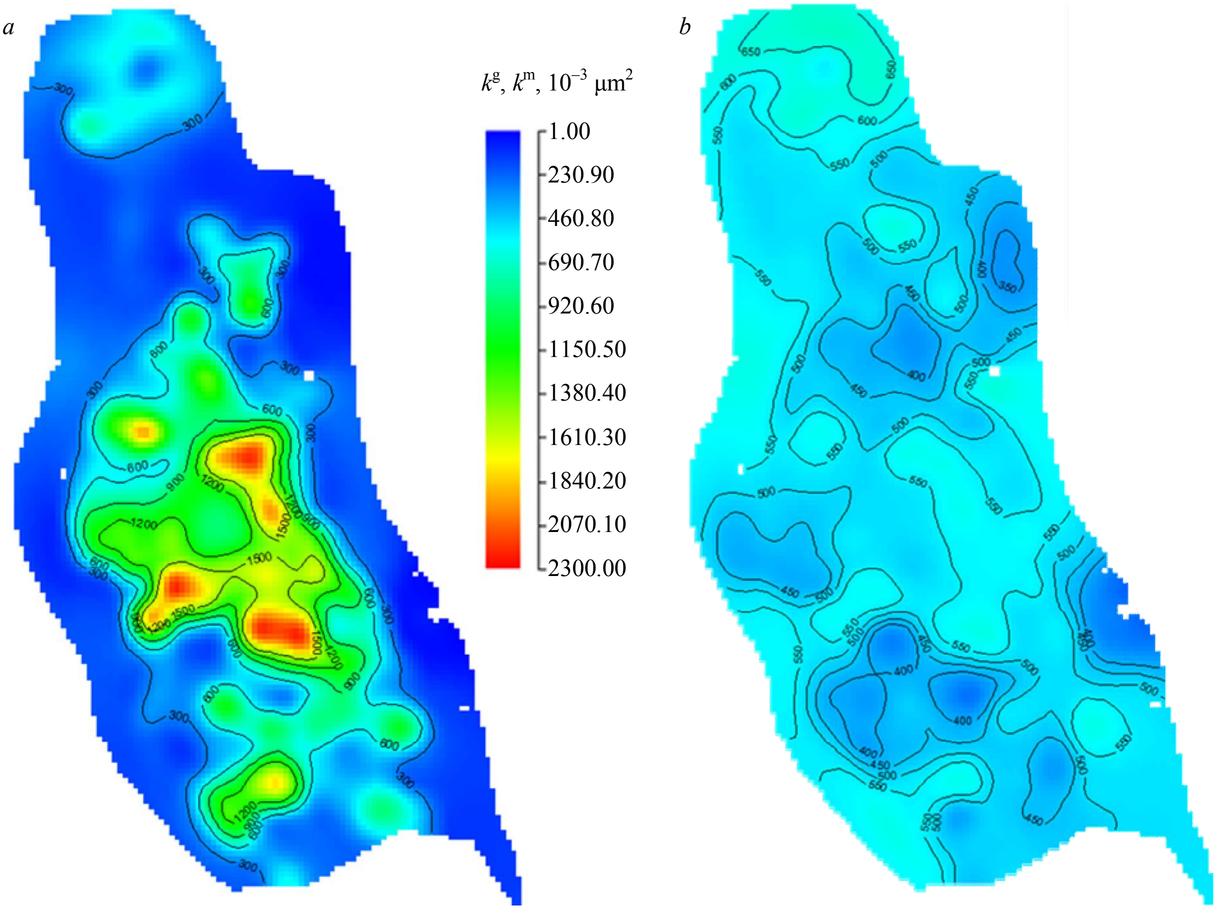

Fig.2.Permeability distribution across the reservoir area: *a* – according to GWT (k^g); *b* – according to the modified method (k^m)

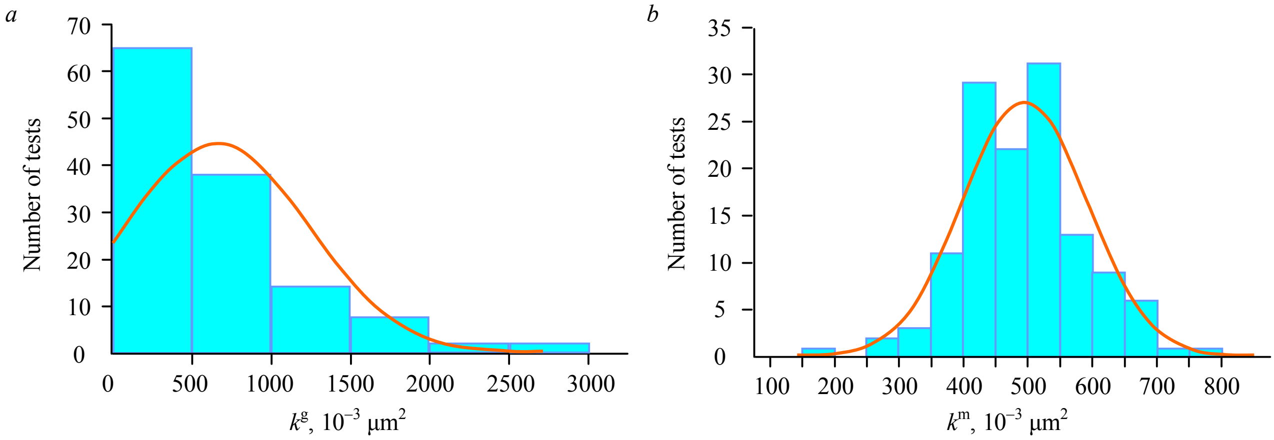

Fig.3. Bar charts of permeability distribution according to GWT data (*a*) and the modified model (*b*)

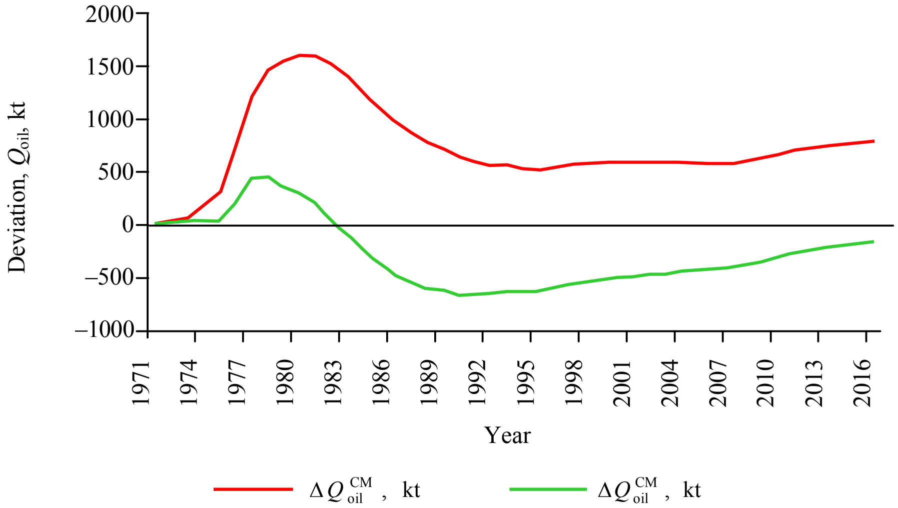

Fig.4. Comparison of deviation from the values of accumulated oil production Q_{oil} for Gondyrev oil field according to conventional (ΔQ_{oil}^{CM}) and modified (ΔQ_{oil}^{MM}) methods of permeability modeling

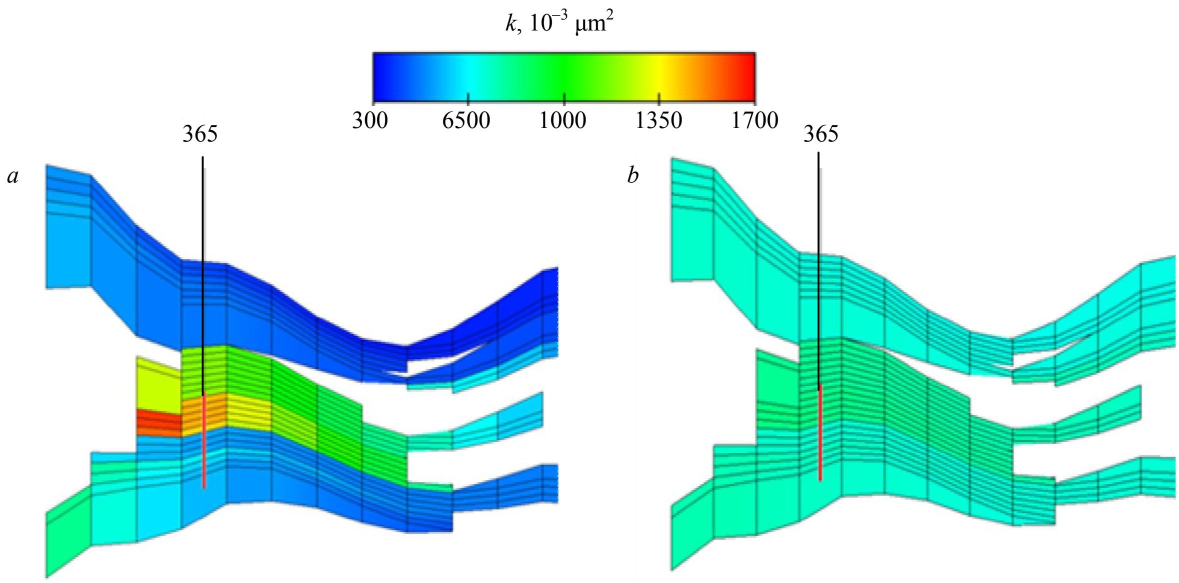

Fig.5. Distribution of permeability parameter *k* in the section of well No. 365, Gondyrev oil field, according to conventional (*a*) and modified (*b*) methods of permeability modeling

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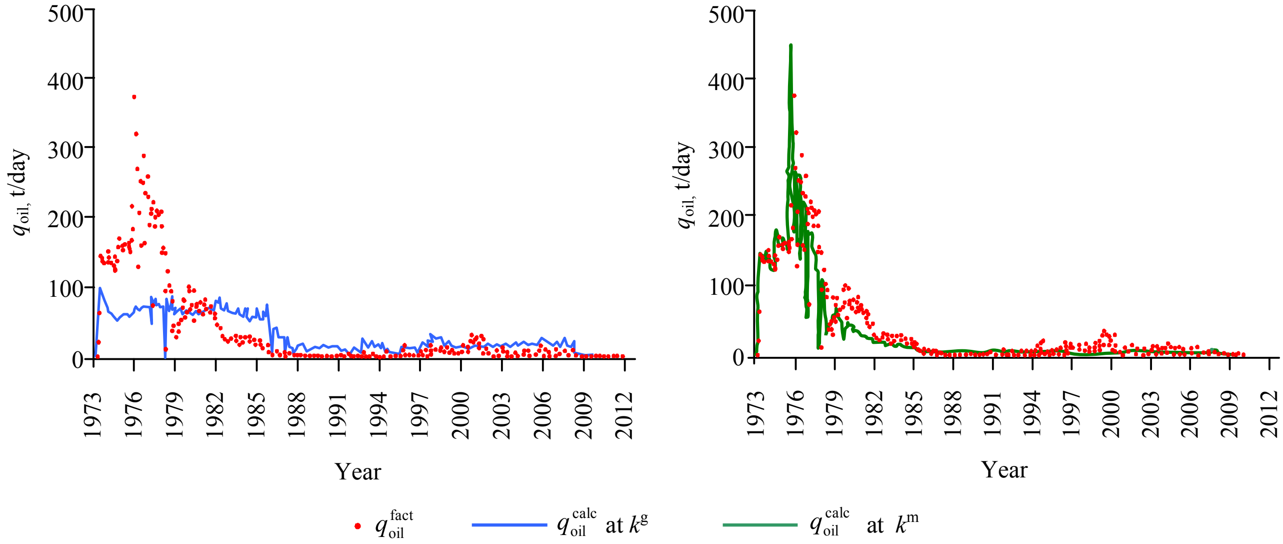

Fig.6.Comparison of calculated q_{oil}^{calc} and actual q_{oil}^{fact} yield of the well No. 365, Gondyrev oil field, for k^g и k^m scenarios

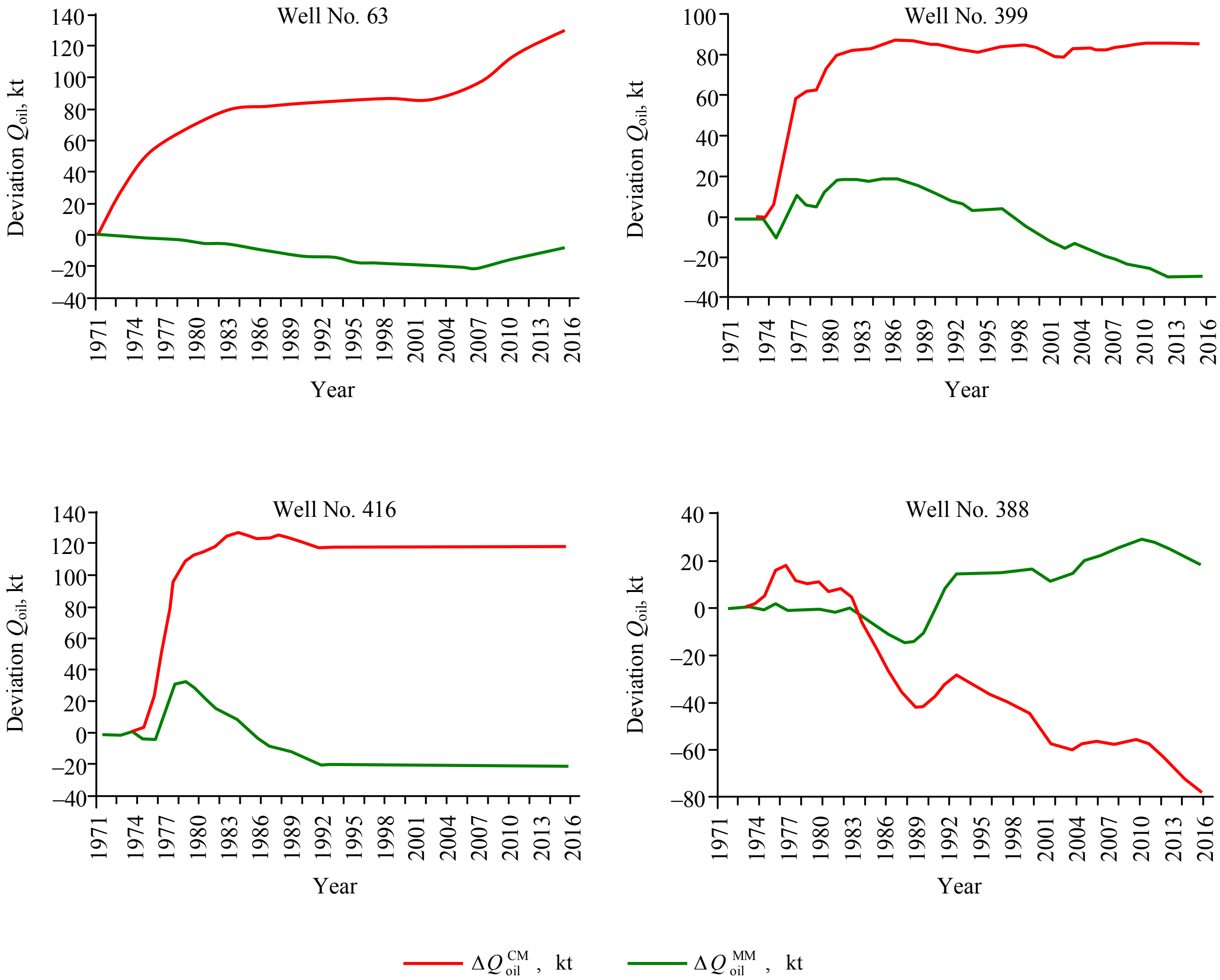

Fig.7. Comparison of deviation from the values of accumulated oil production Q_{oil} for high-rate wells of the Gondyrev oil field according to conventional (ΔQ_{oil}^{CM}) and modified (ΔQ_{oil}^{MM}) methods of permeability modeling

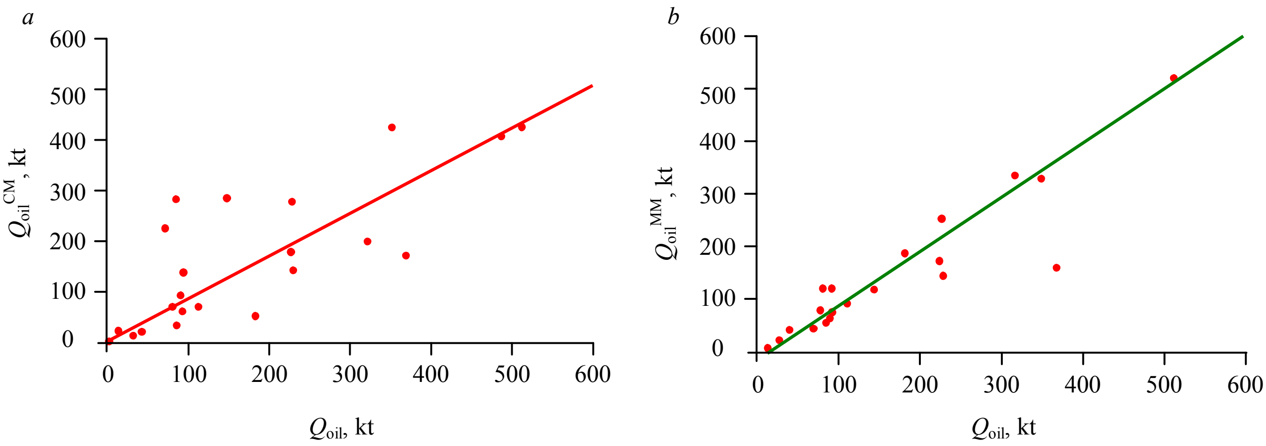

Fig.8. Correlation fields between actual oil production Q_{oil} and calculated production Q_{oil}^{CM} (*a*) and Q_{oil}^{MM} (*b*)

Results of development history adaptation for conventional and modified methods of permeability estimation. For both permeability volumes calculations have been made to reproduce development history for 124 wells of the Visean production facility in Gondyrev oil field. Initially let us compare actual and simulated data on total oil production for both scenarios. Fig. 4 presents how much calculated data of conventional (Q_{oil}^{CM}) and modified (Q_{oil}^{MM}) models deviate from the actual accumulated production (Q_{oil}). The Figure illustrates that along the entire timeline of field development the modified method of permeability assessment provides a better fit between calculated and actual data, especially at the initial stages of exploitation. Besides, the conventional model based on GWT data results in an overestimation of oil production compared to the actual values.

On the example of a high-rate well No. 365 one can see the difference in permeability of a porous collector before and after modification (Fig. 5), as well as actual and modeled data on the well yield (Fig. 6). Obviously, the adaptation of development history using modified permeability is more preferable.

On the whole, the greatest deviations of the conventional model from the actual development history are observed in the initial period. This is illustrated on the example of several high-rate wells having been in operation at the initial stage of field development. Analysis has been carried out for 21 wells. For some of them Fig. 7 shows deviations from actual accumulated production for both calculation methods. One can draw conclusions on the total deviation of analyzed scenarios from actual production using Fig. 8. As seen in the graph, for a modified model there is only one significant deviation from the fact, and there is a good fit between predicted and actual values ($r = 0.92$). Conventional method shows significantly worse results ($r = 0.76$).

Conclusion. Thus, the best fit is observed between the actual oil production and the modified model of permeability estimation. This allows to state that developed method increases the quality of poroperm modeling in the interwell space for a 3D model of Visean pool in the Gondyrev oil field. Density correction allows to make more justified distinctions between Visean collectors of different lithology, which ultimately results in more accurate assessment of residual oil reserves in the deposit in question.

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