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METHOD FOR EVALUATION OF OIL DISPLACEMENT COEFFICIENT BASED ON CONVENTIONAL CORE ANALYSIS

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СПОСОБ ОЦЕНКИ КОЭФФИЦИЕНТА ВЫТЕСНЕНИЯ НЕФТИ НА ОСНОВЕ СТАНДАРТНЫХ ИССЛЕДОВАНИЙ КЕРНА

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oil displacement coefficient, core, analytical dependence, discriminant analysis, regression analysis, statistical model, oil viscosity, porosity, permeability, irreducible water saturation, rock bulk density, conventional core analysis, clastic deposits, carbonate deposits, regression equation.

The article is devoted to the problem of evaluation of oil displacement coefficient. Determination of oil displacement coefficient is essential stage for estimation of recoverable reserves, feasibility study of oil recovery factor and control of field development. Complexity of its laboratory determination is caused by labor intensity and duration of a process. When the number of cores is not enough for flow experiments or absent oil recovery factor is evaluated either similarly to neighbor fields or by analytical dependencies that are important to obtain.
During the generalization and analysis of a significant amount of experimental data the authors developed a method for estimation of oil displacement coefficient without its laboratory determination. A proposed method is based on use of data from previous studies to built statistical models for estimation of displacement coefficient using linear step-by-step regression and discriminant analysis.
In order to implement the method along with oil viscosity, knowledge of reservoir parameters such as porosity, permeability, irreducible water saturation and bulk density of a rock, determined by conventional core studies, is required.
The main stages of implementation of the method for Visean clastic deposits of the Bashkir arch and Solikamsk depression of the Perm Region are presented. Results of implementation of the method for Bashkir carbonate deposits of the indicated tectonic elements are presented as well. Analysis of initial data allow establishing that there are classes of values for which regression equations are statistically justified. According to the equations model and experimental values of the displacement coefficients are very close to each other. It was concluded based on parameters of the equations that there is abnormal influence of initial oil saturation on the displacement coefficient. It is shown that for reservoirs of low flow characteristics a displacement coefficient is determined by their capacitive properties.

Ключевые слова:
коэффициент вытеснения нефти, керн, аналитическая зависимость, дискриминантный анализ, регрессионный анализ, статистическая модель, вязкость нефти, пористость, проницаемость, остаточная водонасыщенность, объемная плотность породы, стандартные исследования керна, терригенные отложения, карбонатные отложения, регрессионное уравнение.

Статья посвящена проблеме оценки коэффициента вытеснения нефти, определение которого является обязательным этапом при подсчете извлекаемых запасов, технико-экономическом обосновании коэффициента извлечения нефти и осуществлении контроля разработки месторождений. Сложность его лабораторного определения обусловлена трудоемкостью и длительностью опытов. При недостаточном для фильтрационных экспериментов количестве керна или его полном отсутствии коэффициент вытеснения оценивается либо по аналогии с соседними месторождениями, либо по аналитическим зависимостям, получение которых является актуальной задачей.
В процессе обобщения и анализа значительного объема экспериментальных данных авторами разработан способ оценки коэффициента вытеснения нефти без его лабораторного определения. Предложенный способ основан на использовании данных ранее проведенных исследований для построения статистических моделей оценки коэффициента вытеснения с использованием линейного пошагового регрессионного и дискриминантного анализа.
Для реализации способа, наряду с вязкостью нефти, требуется знание фильтрационно-емкостных параметров: пористости, проницаемости, остаточной водонасыщенности, а также объемной плотности породы, определяемых при стандартных исследованиях керна.
В работе приведены основные этапы реализации способа для визейских терригенных отложений месторождений Башкирского свода и Соликамской депрессии Пермского края, а также результаты его применения для башкирских карбонатных отложений указанных тектонических элементов. В процессе анализа исходных данных установлено наличие классов значений, для которых статистически обоснованы регрессионные уравнения, демонстрирующие высокую близость модельных и экспериментальных значений коэффициента вытеснения. По параметрам, входящим в уравнения, сделан вывод об исключительном влиянии начальной нефтенасыщенности на коэффициент вытеснения. Показано, что в коллекторах с низкими фильтрационными характеристиками коэффициент вытеснения определяется их емкостными свойствами.

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Introduction

Determination of oil displacement coefficient is essential stage for estimation of recoverable reserves, feasibility study of oil recovery factor and control of field development. To do that it is necessary to conduct laboratory experiments using real core and formation fluids under conditions that simulate natural deposition [1-6]. That causes labor intensity, complexity and duration of a process. If determination of the displacement coefficient is imposible in laboratory then its value is estimated either by analogy with neighbor deposits [7-9] or by analytical dependences [10-15]. Obtaining of those dependencies is an essential task.

For almost a half a century of research on the displacement coefficient in Perm Region a considerable amount of experimental data has been accumulated, including more than 1100 laboratory experiments for 170 fields and 400 development objects. Such amount of statistical data can represent a basis for development of models for estimation of the displacement coefficient.

The authors propose a method that based on values of parameters determined by conventional core studies and known values of oil viscosity allows estimating a value of the displacement coefficient with high accuracy without its laboratory determination [16, 17]. The paper presents the main stages of implementation of this method for oil reserves in the Visean terrigenous deposits and results obtained for the carbonate Bashkir deposits of the Bashkir dome fields and the Solikamsk depression. As a result of the method implementation regression equations are statistically proved. Those equations allow to estimate the displacement coefficient.

Geological and physical characteristics of the object of study

Visean clastic oil and gas bearing complex. The complex is represented by deposits of the Malinovskiy, Tulskiy and Bobrikovskiy formations. The cmplex plays a special role for the oil industry of the Perm Region. More than a half of explored on this teeritory oil reserves are associated with these deposits. Out of 176 developed oil fields (for January 1st 2015) deposits of Visean oil are explored on 134 fields. There are 46 fields out of them located on the territory of the Bashkir dome and 20 on the Solikamsk depression region. Geological and physical conditions within the Bashkir dome can vary significantly. For example, porosity and gas permeability (from core samples) vary from 0.153 to 0.251 unit fraction and from 0.0245 to 3.19 μm^2 respectively, oil viscosity differs from 1.87 to 50 mPa·s. The general trend is that the viscosity within the Bashkir dome increases in the direction from north to south and from east to west.

Porosity of the Visean reservoirs varies within the Solikamsk depression from 0.092 to 0.195 fraction and gas permeability from 0.0126 to 0.922 μm^2. Oil is light and low viscousity compared to most of the deposits of the Bashkir dome. It varies from 0.75 to 6.6 mPa·s.

Bashkir carbonate deposits. They are on the second place in terms of hydrocarbon reserves in the territory of the region. Oil deposits are explored in 77 developed deposits, 21 of them are located within the Bashkir dome, 16 are confined to the Solikamsk depression. Porosity of Bashkir reservoirs within dome boundaries varies from 0.124 to 0.226 fraction, gas permeability varies from 0.0214 to 0.576 μm^2. Bashkir oil of the same dome in average is lighter than the Visean one. Viscosity varies from 5.7 to 16.4 mPa·s.

Productive deposits of the Solikamsk depression fields have smaller values of porosity from 0.114 to 0.170 fraction, gas permeability from 0.0062 to 0.180 μm^2 and oil viscosity from 0.88 to 13 mPa·s.

Visean clastic deposits

Bashkir dome

Initial sample for Visean clastic deposits was compiled using 71 laboratory measurements of the displacement coefficient (Table 1). The sample encompases 27 fields of the Bashkir dome.

Using these data correlation fields were constructed and correlation coefficients *r* are determined (see the matrix).

Table 1

Summary of laboratory measurements of the displacement coefficient in the Visean clastic deposits of the Bashkir dome

No.	Field	K_p, fractions	$K_{g.perm}$, μm^2	$K_{i.w}$, fractions	ρ, g/cm^3	μ_o, mPa·s	$K_{p/\rho}$, cm^3/g	$K_{g.perm}/\mu_o$, μm^2/(mPa·s)	K_{disp}, fractions
1	Byrkinskoe	0.166	0.1130	0.226	2.16	8.40	0.0769	0.01345	0.500
2	Trifonovskoe	0.174	0.0245	0.461	2.17	5.37	0.0802	0.00456	0.500
3	Kalmiyarskoe	0.163	0.0461	0.179	2.22	8.20	0.0734	0.00562	0.526
4	Gondyrevskoe	0.222	0.2058	0.100	2.06	10.30	0.1078	0.01998	0.527
5	Yuzhinskoe	0.189	0.1124	0.111	2.15	11.70	0.0879	0.00961	0.528
…	…	…	…	…	…	…	…	…	…
71	Krasnoyarsko-Kuedinskoe	0.229	3.1900	0.040	2.03	13.10	0.1128	0.24351	0.720

Correlation matrix for Bashkir dome sample

	K_p, fractions	$K_{g.perm}$, μm^2	$K_{i.w}$, fractions	ρ, g/cm^3	μ_o, mPa·s	$K_{p/\rho}$, cm^3/g	$K_{g.perm}/\mu_o$, μm^2/(mPa·s)	K_{disp}, fractions
K_p, fractions	1.00	**0.68** **0.000**	**–0.60** **0.000**	**–0.94** **0.000**	**0.37** **0.002**	**0.99** **0.000**	**0.31** **0.009**	**0.58** **0.000**
$K_{g.perm}$, μm^2		1.00	**–0.53** **0.000**	**–0.70** **0.000**	**0.37** **0.000**	**0.70** **0.000**	**0.53** **0.000**	**0.68** **0.000**
$K_{i.w}$, fractions			1.00	**0.57** **0.000**	–0.19 0.115	**–0.60** **0.000**	**–0.40** **0.001**	**–0.68** **0.000**
ρ, g/cm^3				1.00	**–0.36** **0.000**	**–0.96** **0.000**	**–0.35** **0.003**	**–0.58** **0.000**
μ_o, mPa·s					1.00	**0.38** **0.001**	**–0.36** **0.002**	–0.05 0.683
$K_{p/\rho}$, cm^3/g						1.00	**0.32** **0.007**	**0.59** **0.000**
$K_{g.perm}/\mu_o$, μm^2/(mPa·s))							1.00	**0.66** **0.000**
K_{disp}, fractions								1.00

Note: a numerator in the cells represents a value of correlation coefficient, a denominator represents a level of statistical significance (p); bold means statistically significant correlation coefficients for which $p < 0.05$.

The correlation matrix shows that almost all the studied parameters correlate well with each other. Neverthelles, there are two pairs of links that have no significant connection. Those pairs are viscosity of oil and irreducible water saturation, viscosity of oil and K_{disp}.

According to the data of the sample performed by the method of stepwise regression analysis [18-25], a multidimensional equation was constructed to estimate model values of the displacement coefficient:

$$K_{disp}^{m} = 0,6056 + 0,0265 K_{g.perm} - - 0,3229 K_{i.w} + 0,1921 \frac{K_{g.perm}}{\mu_o} \quad (1)$$

when $R^2 = 0.69$, $p < 10^{-5}$, $N = 71$, where R^2 is a coefficient of determination; N is sample volume.

An order of the parameters in the regression equation determines a degree of their influence on the displacement coefficient. For example, value K_{disp}^{m} in the equation (1) is formed firstly under the influence of rock gas permeability and then by values of residual water saturation and a ratio $K_{g.perm}/\mu_o$.

Model and experimental values of K_{disp} are compared in the Fig. 1.

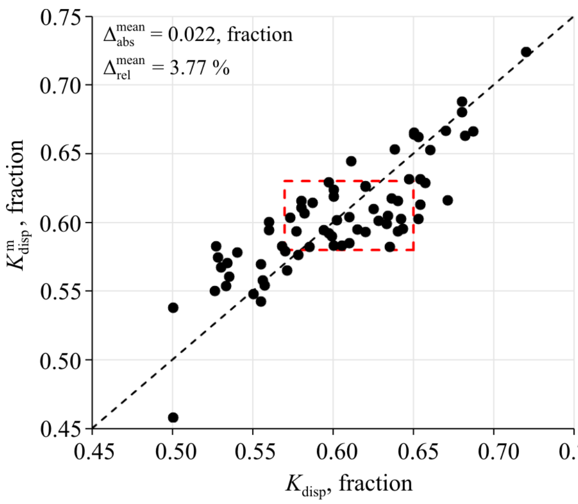

Fig. 1. Correlation field of model and experimental values K_{disp}

There are three ranges of values can be distinguished on the Fig. 1 such as:

1) model values of K_{disp} exceed experimental to the left of the red rectangle;

2) model values of K_{disp} are below experimental to the right of the red rectangle;

3) model and real values of K_{disp} do not have strong correlation between in the red rectangle. Similar results were obtained in [26] during processing a sample of a smaller volume. Hence, it can be assumed that a displacement coefficient value for the selected groups is affected by various indicators.

In order to confirm this assumption correlation dependencies of reservoir characteristics are studied in detail. For example, it is possible to determine from the dependence of the mobility coefficient ($K_{mob} = K_{g.perm}/\mu_o$) from viscosity (Fig. 2) that there are three groups of values such as:

1) within the interval of values K_{mob} from the maximum value 0.353 to 0.123 μm²/mPa·s where K_{mob} changes most intensively if viscosity is increased;

2) within the interval of values K_{mob} that correspond to change of μ_o from 17.7 to 0 mPa·s where values of K_{mob} change slightly if the viscosity is increased;

3) link between the change in K_{mob} and μ_o is weak or null.

Values dedicated to selected groups have also not so ctrong relationship in the coordinates "permeability - mobility coefficient" (Fig. 3).

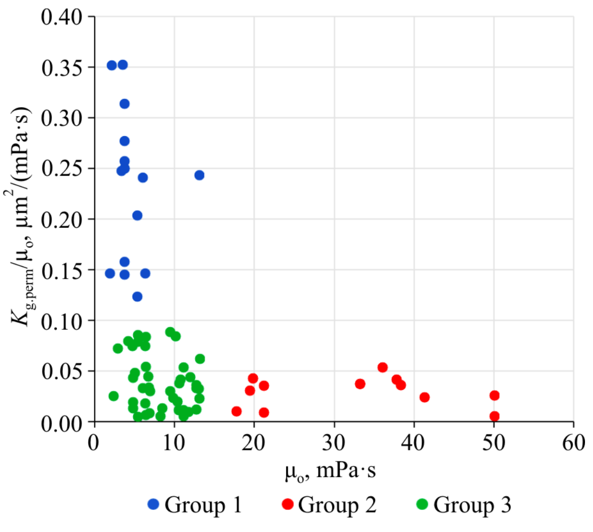

Fig. 2. Change in a mobility coefficient depending on oil viscosity

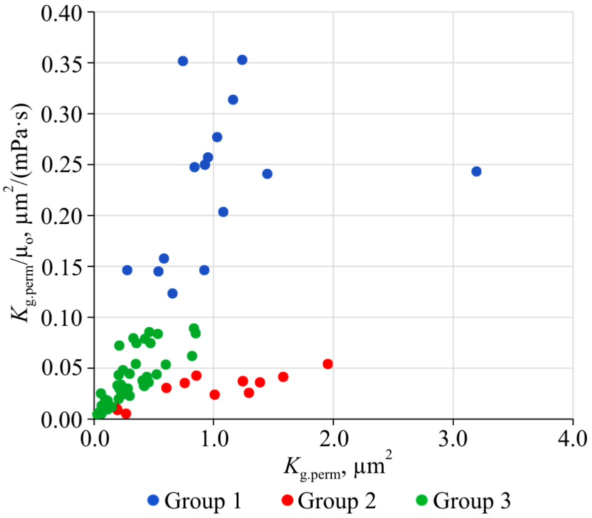

Fig. 3. Dependence of a mobility coefficient on permeability

In order to estimate an oil displacement coefficient using stepwise regression analysis multidimensional equations for selected groups (classes) are obtained:

– for the 1st class

$$K_{disp}^{m1} = 0.5883 - 0.3541 K_{i.w} + 0.0291 K_{g.perm} + 0.2358 \frac{K_{g.perm}}{\mu_o} \quad (2)$$

when $R^2 = 0.82$, $p < 10^{-4}$, $N = 16$;

– for the 2nd class

$$K_{disp}^{m2} = -0.5486 - 0.7384 K_{i.w} + 1.9497 K_p + 0.3784 \rho \quad (3)$$

when $R^2 = 0.85$, $p < 3.4\cdot10^{-4}$, $N = 13$;

– for the 3rd class

$$K_{disp}^{m3} = 0.8217 + 0.9362 \frac{K_{g.perm}}{\mu_o} - 0.1975 K_{i.w} - 0.1161 \rho \quad (4)$$

when $R^2 = 0.65$, $p < 10^{-5}$, $N = 42$.

Values of $p < 0.05$ indicate statistical significance of the equations obtained.

Model values calculated by the equations (2)-(4) and experimental ones K_{disp} are quite close to the line of equal values (see Fig. 4). Correlation coefficients r are equal to 0.91 and 0.93 when $p < 10^{-5}$ in both cases. The correlation field of the third class values, when $K_{disp} < 0.6$, in general is

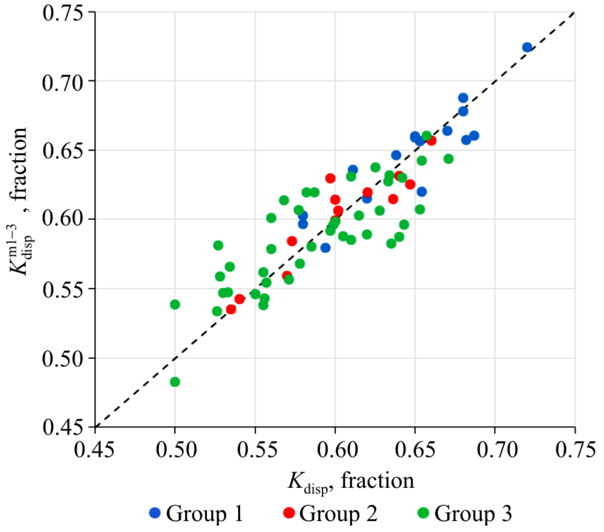

Fig. 4. Correlation field of model and experimental values of K_{disp} for the three classes

higher than the line of equal values, i.e. migrated towards model ones. When $K_{disp} > 0.6$ it is migrated towards experimental ones. From that it can be assumed that the sample for the third class unites two groups of values with a border between them around $K_{disp} = 0.6$. Therefore, a stepwise regression analysis was performed with construction of equations first for three values ($N = 3$), then for four ($N = 4$) and so on untill $N = 42$ (Table 2). That allowed to trace in dynamics the influence of parameters on the displacement coefficient.

There is in the obtained regression equations of up to $N = 20$ ($K_{disp} < 0.6$) a capacitive parameter "irreducible water saturation K_{disp}" is on the first place. That parameter then is replaced by flow parameters such as $K_{g.perm}/\mu_o$, i.e. different parameters in groups influence K_{disp}. That is confirmed by the values of regression coefficients for parameters in the equations. For example, depending on K_{disp} values of coeficients of K_{disp} and μ_o have extremes in the area $K_{disp} = 0.61$ (Fig. 5).

Table 2

Multidimensional equations of stepwise regression analysis of the 3rd class data of Vesean clastic deposits of Bashkir dome

No.	Equation	Coefficient
3	$K_{disp}^{m} = -0.4985 + 0.4613\rho$	$R^2 = 0.98$ $p < 0.099$
4	$K_{disp}^{m} = 0.5314 - 0.0753K_{i.w}$	$R^2 = 0.58$ $p < 0.236$
5	$K_{disp}^{m} = 0.5337 - 0.0813K_{i.w}$	$R^2 = 0.65$ $p < 0.101$
…		…
41	$K_{disp}^{m} = 0.9070 - 0.0628\frac{K_{g.perm}}{\mu_o} - 0.2721K_{i.w} - 0.1262\rho - 0.0060\mu_o$	$R^2 = 0.67$ $p < 10^{-5}$
42	$K_{disp}^{m} = 0.8217 - 0.9362\frac{K_{g.perm}}{\mu_o} - 0.1975K_{i.w} - 0.1161\rho$	$R^2 = 0.65$ $p < 10^{-5}$

There is an extremum on the graph at $K_{disp} = 0.60$ for the dependence of determination coefficient R^2 on displacement coefficient (Fig. 6). It means that up to this value approximation reliability increases and then decreases after. That proves that parameters works well at the left part of the graph and less in the right part.

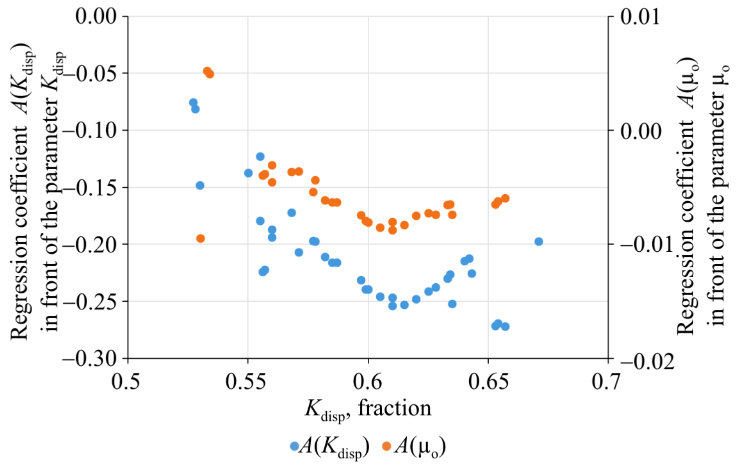

Fig. 5. Dependences of the coefficients of $K_{i.w}$ and μ_o on K_{disp} in the equations during stepwise regression analysis for Visean clastic deposits of the Bashkir dome

Values of R^2 that were close to 1 were not considered because they correspond to equations built by a minimum amount of data. An extremum in the area K_{disp} = 0.55 can be explained by a local change in parameters of equations and enaibling of parameter "bulk density of rock ρ".

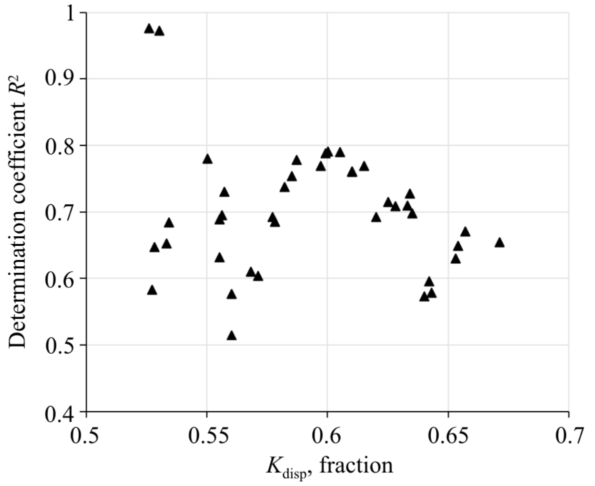

Fig. 6. Dependence of a determination coefficient on K_{disp} for stepwise regression analysis for Visean clastic deposits of the Bashkir dome

Based on the analysis performed it was established that the sample of the third class includes two subclasses with a relative boundary between them in the region of K_{disp} = 0.6, which R^2 corresponds to. Data belonging to the first or second subclass is determined more precisely by linear discriminant analysis (LDA) [27-29]. The linear discriminant function (LDF) that divides the sample according to the values of a mobility coefficient, irreducible water saturation and density is

$$Z = -15.5681 + 91.7717\frac{K_{g.perm}}{\mu_o} + 6.3586K_{i.w} + 5.3255\rho \quad (5)$$

when R^2 = 0.79, $p < 10^{-5}$. For values of $Z < 1.2$ data belong to the first subclass and to the cesond subclass if values bigger than 1.2.

For selected subclasses following regression coefficients are obtained for evaluation of K_{disp}:

– for the 1st subclass of the 3rd class

$$K_{disp}^{m3-1} = 0.5501 - 0.1500K_{i.w} + 1.7990\frac{K_{g.perm}}{\mu_o} \quad (6)$$

when $R^2 = 0.62$, $p < 10^{-5}$, $N = 31$;

– for the 2nd subclass of the 3rd class

$$K_{disp}^{m3-2} = 0.5214 + 2.0426\frac{K_{g.perm}}{\mu_o} - 0{,}6285K_{i.w} \quad (7)$$

when $R^2 = 0.77$, $p < 5.18\cdot10^{-3}$, $N = 11$.

Equations (6) and (7) include some parameters, but differ in the values of the regression coefficients.

As a result of subclasses allocation the correlation field is uniformly distributed along a line of equal values (Fig. 7*b*) and consists of three areas (if $K_{disp} < 0.57$ that is the area of 1st subclass values; if $K_{disp} > 0.63$ that is the area of 2nd subclass; if $0.57 < K_{disp} < 0.63$ that is transition area from the 1st to the 2nd subclasses), that transit smoothly to each other. Accuracy of model values K_{disp} estimation for the third class generally has increased in comparison with a case that has no subclasses allocation (Fig. 7*a*).

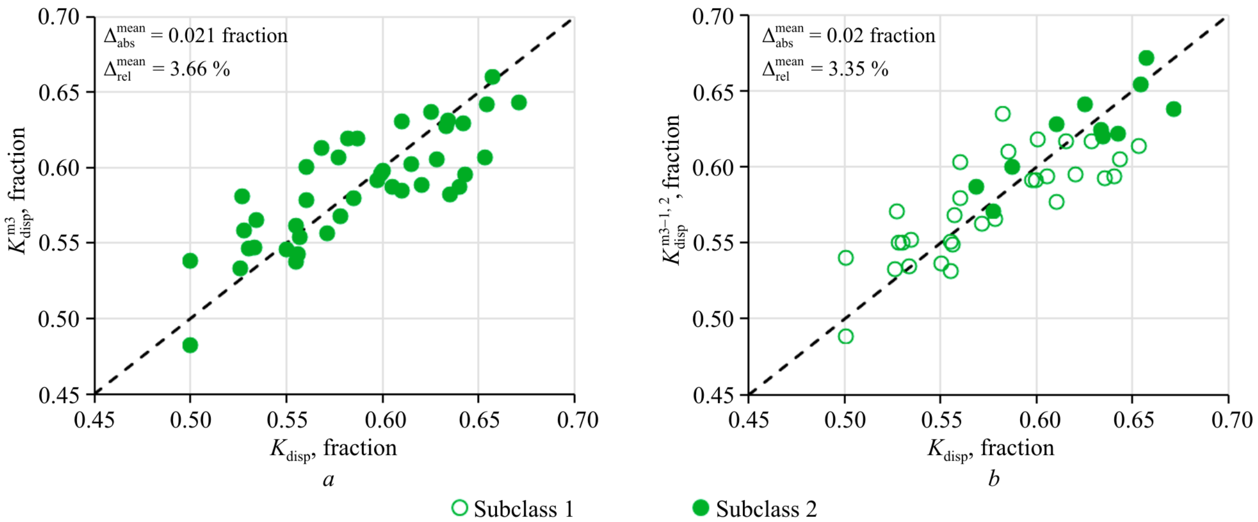

Fig. 7. Comparison of model and experimental values of K_{disp} for the 3rd class before (*a*) and after (*b*) the allocation of subclasses

Thus, the sample for Visean deposits of Bashkir dome fields was described by four regression equations (2), (3), (6) and (7), which reduced the relative error in estimation of model values of K_{disp} (Fig. 8).

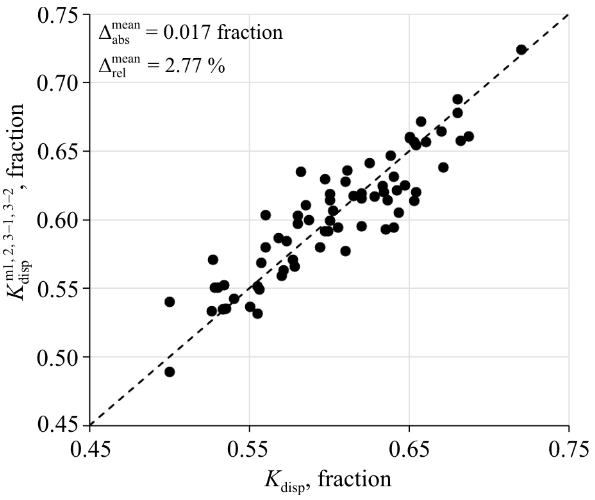

Fig. 8. Comparison of the model and experimental values of K_{disp} after the selection of classes and subclasses in the initial sample for Visean clastic deposits of Bashkir dome fields

Solikamsk depression

Initial sample for clastic deposits of the Visean age of Solikamsk depression fields, considered in [30], was extended to 46 measurements of K_{disp}.

Based on the sample data correlation fields are constructed and correlation coefficients r are determined (see matrix).

The correlation matrix shows that all the parameters studied correlate well with each other except for oil viscosity. A multidimensional regression equation was obtained for the entire sample.

$$K_{disp}^{m} = 0.6978 - 0.4725 K_{i.w} + 0.0943 \frac{K_{g.perm}}{\mu_o} \quad (8)$$

when $R^2 = 0.69$, $p < 10^{-4}$, $N = 46$.

Comparison of values calculated from equation (8) and experimental values of K_{disp} (Fig. 9) showed that the correlation field at $K_{disp} < 0.62$ (to the left of the red line) has a larger scatter of values compared to the right-hand side of the field, where model values of K_{disp} are substantially lower than experimental ones.

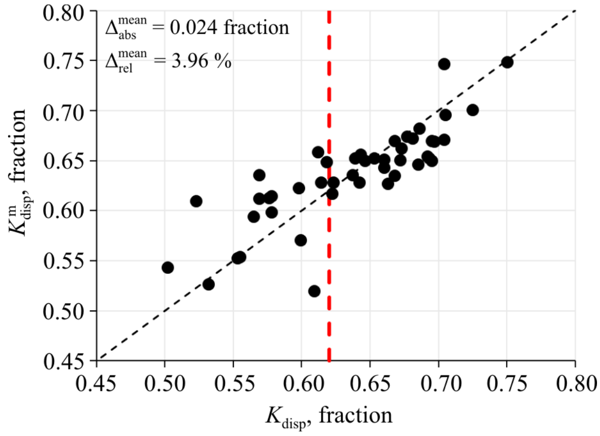

Fig. 9. Correlation field of model and experimental values of K_{disp} in Visean clastic deposits of Solikamsk depression fields

Correlation matrix for Solikamsk depression sample

	K_p, fractions	$K_{g.perm}$, μm^2	$K_{i.w}$, fractions	ρ, g/cm^3	μ_o, mPa·s	$K_{p/\rho}$, cm^3/g	$K_{g.perm}/\mu_o$, μm^2/(mPa·s)	K_{disp}, fractions
K_p, fractions	1.00	**0.81** **0.000**	**–0.66** **0.000**	**–0.96** **0.000**	0.04 0.776	**0.99** **0.000**	**0.67** **0.000**	**0.65** **0.000**
$K_{g.perm}$, μm^2		1.00	**–0.54** **0.000**	**–0.72** **0.000**	–0.05 0.766	**0.82** **0.000**	**0.91** **0.000**	**0.61** **0.000**
$K_{i.w}$, fractions			1.00	**0.69** **0.000**	–0.20 0.184	**–0.66** **0.000**	**–0.42** **0.004**	**–0.76** **0.000**
ρ, g/cm^3				1.00	–0.01 0.926	**–0.96** **0.000**	**–0.60** **0.003**	**–0.61** **0.000**
μ_o, mPa·s					1.00	0.03 0.834	–0.28 0.058	–0.04 0.792
$K_{p/\rho}$, cm^3/g						1.00	**0.68** **0.007**	**0.66** **0.000**
$K_{g.perm}/\mu_o$, μm^2/(mPa·s)							1.00	**0.55** **0.000**
K_{disp}, fractions								1.00

Similarly to Visean clastic deposits of the Bashkir dome, it can be assumed that the K_{disp} in the left and right parts of the correlation field relative to the red line is influenced by various parameters.

That is confirmed by a dependence of the determination coefficient R^2 on K_{disp} (Fig. 10), obtained by stepwise regression analysis with the construction of equations first for $N = 3$ sample values, then for $N = 4$ and so on until $N = 46$. This dependence tends to decrease to $K_{disp} = 0.62$, and increase after inflection and then divides the sample into two classes.

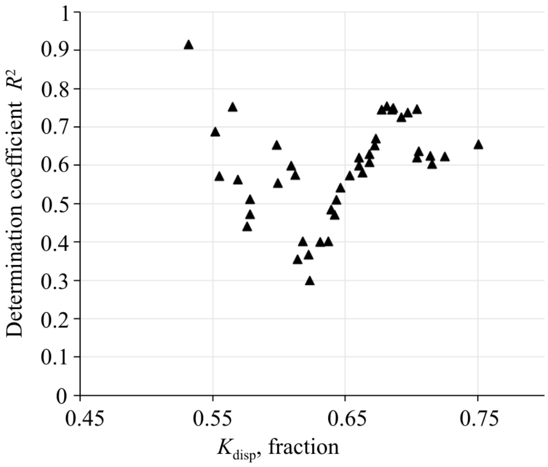

Fig. 10. Dependence of determination coefficient on K_{disp} in stepwide regression analysis for Visean clastic deposits of Solikamsk depression fields

In order to determine the class LDA is used. The discriminant function Z, which divides the sample into two classes looks like

$$Z = -56.7220 + 132.0232K_{p} - \\ -13.2649K_{i.w} - 5.3172K_{g.perm} + 17.8673\rho \quad (9)$$

when $R^2 = 0.77$, $p < 10^{-5}$, $N = 46$.

Having $Z < -0.5$ data belong to the first class, and to the 2nd if $Z > -0.5$. After two classes in the the initial sample were selected linear regression equations for them were obtained:

– for the 1st class

$$K_{disp}^{m1} = -0.5483 - 0.2514K_{i.w} + 0.4811\rho + \\ + 2.6959\frac{K_{g.perm}}{\mu_o} - 1.1552K_{g.perm} + 0.0159\mu_o \quad (10)$$

when $R^2 = 0.79$, $p < 1.94\cdot10^{-3}$, $N = 18$;

– for the 2nd class

$$K_{disp}^{m2} = 0.7885 - 0.0759\frac{K_{g.perm}}{\mu_o} - \\ - 0.7088K_{i.w} - 0.0203\mu_o + 0.0671K_{g.perm} \quad (11)$$

when $R^2 = 0.84$, $p < 10^{-5}$, $N = 28$.

Comparison of model and experimental values of K_{disp} (Fig. 11) showed that they control each other quite well ($R = 0.93$). At the same time, model values of the displacement coefficient now can be estimated with less error in comparison with the case where no classes are selected.

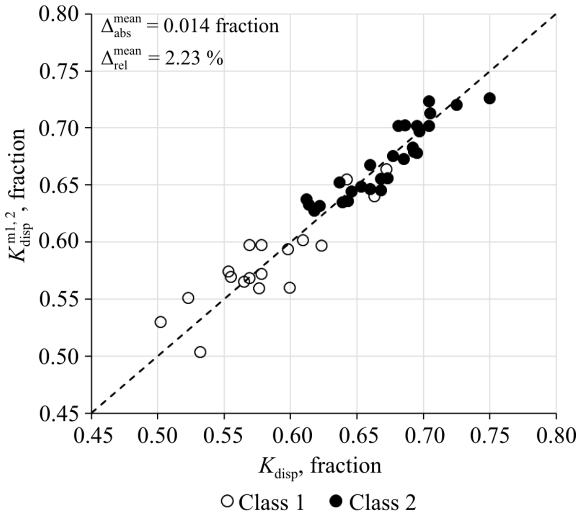

Fig. 11. Comparison of experimental and model values of K_{disp} for two classes of Visean clastic deposits of Solikamsk depression fields

Carbonate Bashkir deposits

Using the mentioned approach, data for Bashkir carbonate deposits of Bashkir dome fields and Solikamsk depression were analyzed.

In order to classify data from the Bashkir dome LDF is obtained:

$$Z = 96.2606 + 48.8722K_{i.w} - \\ - 41.1925\rho - 78.8568K_{p} \quad (12)$$

when $R^2 = 0.77$ and $p < 3\cdot10^{-5}$.

When $Z > 0$ data belong to the 1st class and when $Z < 0$ it belong to the 2nd one.

A displacement coefficient in the productive Bashkir deposits of the Bashkir dome is estimated by equations with high values of the determination coefficient, that are as follows:

– for the 1st class

$$K_{disp}^{m1} = 6.2282 - 0.5105K_{i.w} + \\ + 0.0122\mu_o - 2.2167\rho - 4.3314K_{p} \quad (13)$$

when $R^2 = 0.98$, $p < 0,0014$;

– for the 2nd class

$$K_{disp}^{m2} = 1.9903 - 0.0076\mu_o + \\ + 0.1579K_{g.perm} - 1.4349K_{p} - 0.4935\rho \quad (14)$$

when $R^2 = 0.95$, $p < 0.0021$.

Comparison of experimental values and values calculated in accordance with equations (13) and (14) of the K_{disp} (Fig. 12*b*) shows, that they control each other quite well (r = 0.99). At the same time, mean relative error in the estimation of K_{disp} decreased in 3.7 times in comparison with the case where no classes were allocated (Fig. 12*a*). The equations obtained in this paper approximate the sample better than in [31].

Equations for two classes of Bashkir Carbonate deposits of Solikamsk depression fields are obtained in the same way:

– for the 1st class

$$K_{disp}^{m1} = 1.1483 - 5.6251 K_{g.perm} + 0.1718 \mu_o + 16.1795 \frac{K_{g.perm}}{\mu_o} - 0.4404 \rho - 0.1534 K_{i.w} \quad (15)$$

when $R^2 = 0.99$, $p < 0.0026$;

– for the 2nd class

$$K_{disp}^{m2} = 0.5712 + 0.1914 K_{g.perm} + 0.2823 \frac{K_{g.perm}}{\mu_o} \quad (16)$$

when $R^2 = 0.40$, $p < 0.077$.

At that, the first class includes data for which the value of the discriminant function (17) is greater than 0.5 and $Z < 0.5$ for the second one:

$$Z = 101.442 - 191.381 K_p + 29.490 K_{i.w} + 13.620 K_{g.perm} - 35.118 \rho \quad (17)$$

when $R^2 = 0.84$, $p < 7 \cdot 10^{-6}$.

Model values of K_{disp} calculaterd using equations (15), (16) correlate with experimental ones quite good (Fig. 13).

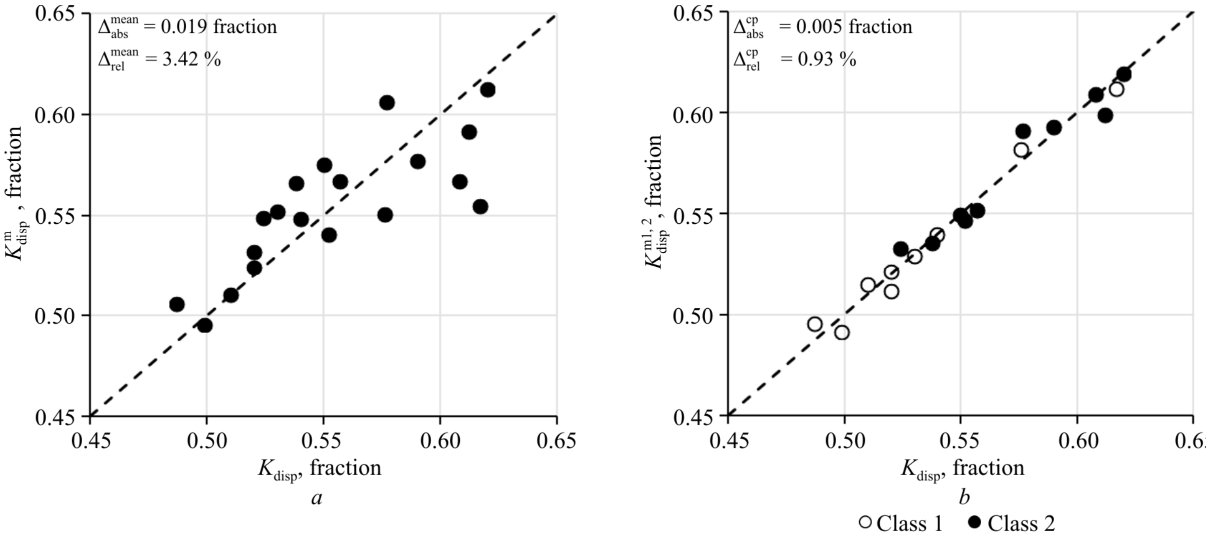

Fig. 12. Comparison of experimental and model values of a displacement coefficient before (*a*) and after (*b*) allocation into the classes of a sample of Bashkirian carbonate deposits of Bashkir dome fields

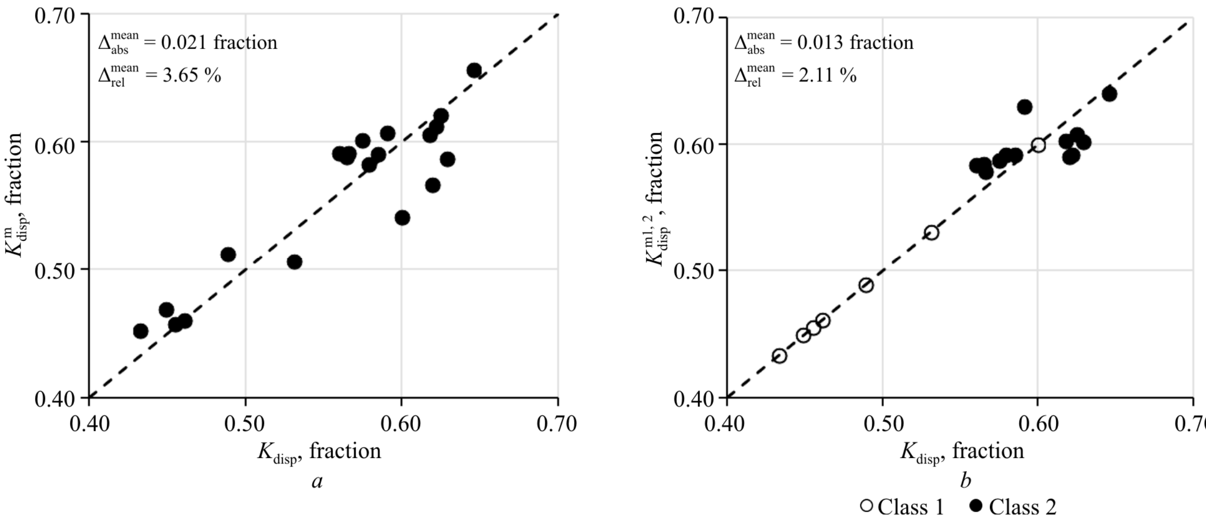

Fig. 13. Comparison of model and experimental values of a displacement coefficient before (*a*) and after (*b*) allocation into the classes of a sample of Bashkirian carbonate deposits of Solikamsk depression fields

Conclusion

As a result of the performed studies the following conslusions were obtained:

1. A value of oil displacement coefficient in clastic deposits is influenced mainly by the irreducible water saturation or initial oil saturation of the rock.
2. A coefficient of oil displacement in carbonate rocks is formed mainly due to their reservoir properties.
3. The parameter “oil viscosity” takes part in the formation of values of a displacement coefficient both in clastic and carbonate deposits.
4. The proposed method allows estimating a value of the displacement coefficient with no laboratory determination using conventional core studies and oil viscosity data.

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