**Multi-Variable Model of Oil Displacement Efficient by Water for Carbonate Reservoirs of Bukhara-Khiva Region of Uzbekistan**

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**Abstract.** The article presents the results of study of rock fracturing, gas cap, reservoir regime, oil viscosity, formation water salinity and heterogeneity of productive horizons which are the main criteria of applicability of physical and chemical methods of increasing oil recovery coefficient as well as a sequence of experimental works on determination of oil displacement coefficient by water. It is shown that single-factor models of oil displacement coefficient by water of different types under similar geological and physical conditions give incomparable results. Multi-factor models of CODW (coefficient of oil displacement by water) are created on the basis of correlation and regression analysis. It is established that in carbonate reservoirs of depression and reef facies the main influence on oil displacement coefficient by water is exerted by formation flushing coefficient. The results of assessing the oil displacement coefficient by water based on the actual data of oil deposit development in the Bukhara-Khiva region, represented by carbonate rocks of depression and reef deposits have been shown. A wide range of variations in the achieved values of the oil displacement coefficient by water has been established. As well as, the results of experimental studies of oil displacement by water. Using the software product “Gurve Expert1.4”, the results of experimental studies have been processed, and the dependences of the oil displacement coefficient by water on geological, physical and complex parameters have been established.

**Keywords:** region, deposits, reservoir, displacement, coefficient, porosity.

**INTRODUCTION**

In connection with the widespread use of various methods of flooding oil reservoirs and the need to improve their efficiency. The study of the process of oil displacement by water is an urgent task of the oil industry [1]

Research is being conducted worldwide to improve the oil-washing properties of water injected into the reservoir, to develop criteria for the effective use of physicochemical methods and to provide a technical and economic justification for the feasibility of their implementation [2]. In this regard, special attention is paid to the study of factors affecting the CODW and the creation of scientifically sound models for its determination in various geological and physical conditions of oil deposits [3].

The models for calculating the displacement coefficient proposed to date are obtained mainly in the form of single-factor dependencies on the average permeability and temperature of the reservoir, the viscosity of reservoir oil, the heterogeneity of the reservoir, the specific filtration surface and the volume of pumped liquid, as well as on a set of parameters characterizing the geological and physical conditions of the deposits and the properties of the reservoir fluids [4].

Experience in field development shows that the oil displacement coefficient by water is affected by a large number of factors related to both the properties of rocks and formation fluids. As a result, the value of the CODW determined by the proposed models varies within wide limits [5]. One of the scientifically sound ways to solve this problem is to build multifactor models for determining the CODW [14].

**METHODS**

Currently, correlation and regression analysis are widely used to identify the statistical relationship between factors and the process indicator [6]. The theoretical foundations for the application of correlation and regression analysis are given in the work "Mathematical Theory of Experiment in Oil and Gas Production" [7]. According to this method, correlation coefficients are used to evaluate the statistical relationship, which are calculated using the formula

*ryx==*

*=,* (1)

where *ryx* is the correlation coefficient between the process indicator and one of the factors; and are the mathematical expectation; and dispersions calculated by the formulas:

2  (2)

2 (3)

The reliability of the correlation coefficient value is assessed by the reliability criterion

θ, (4)

where the standard deviation of the correlation coefficient

σr =. (5)

With the criterion , with a probability of 0.95, it can be asserted that a linear correlation relationship exists between the analyzed parameters [8]. Correlation coefficients allow us to estimate the degree of linear statistical relationship between indicators and factors, as well as between the factors themselves [9]. For example, if the correlation coefficient is close to one, this means that the functional relationship is linear, and a positive correlation coefficient indicates direct proportionality, and a negative one indicates inverse proportionality [10]. Correlation coefficients close to zero mean the absence of a linear statistical relationship [11].

The results of correlation analysis are the source material for constructing empirical formulas, called regression equations or mathematical models in statistics [12].

A linear regression equation has the form:

, (6)

where - are the coefficients of the regression equation determined from the solution of the system of equations

σy=

σy=

σy=, (7)

and the coefficient

(8)

The main advantage of correlation and regression analysis is that this method allows us to establish not only the qualitative but also the quantitative influence of various factors on the process indicator, in our studies on the oil displacement coefficient by water.

**RESULTS AND DISCUSSION**

The derivation of the regression equation for the oil displacement coefficient by water for carbonate rocks of the Bukhara-Khiva region given in Table 1. The calculations investigated the influence of four factors on the coefficient of oil displacement by water (Kod, fractions of units): coefficient of formation flushing (Vpor, fractions of units), coefficient of initial water saturation (Kw, fractions of units), coefficient of porosity (m, fractions of units) and coefficient of heterogeneity (S, fractions of units).

Table 3 shows the values of the correlation coefficients, average values of the factors and standard deviations. The results of intermediate calculations for the coefficient of formation flushing are given in Table 2.

**TABLE 1.** Factor values for carbonate rocks

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **№** | Fields | Horizon | Factors | | | | Heterogeneity coefficient,  fractions of units. |
| Coefficient of oil displacement by water, fractions of units | Coefficient of formation flushing, fractions of units | Coefficient of water saturation, fractions of units | Porosity coefficient, fractions of units. |
| 1 | Kruk | XV-ПР+XV-P | 1,128 | 0,20 | 0,17 | 2,8200 | 0,406 |
| 2 | Western Yulduzas | XV+XVa | 0,905 | 0,35 | 0,16 | 16,0771 | 0,459 |
| 3 | Western Tashli | XVa | 0,162 | 0,23 | 0,13 | 3,4130 | 0,052 |
| 4 | Eastern Tashli | XVI | 0,918 | 0,10 | 0,16 | 2,2773 | 0,550 |
| 5 | Northern Urtabulak | XV-HР+XV-P | 0,369 | 0,25 | 0,15 | 2,8522 | 0,049 |
| 6 | Umid | XV-HР+XV-P | 0,396 | 0,22 | 0,12 | 3,5435 | 0,377 |
| 7 | Karaktoy | XV+XVa | 0,348 | 0,31 | 0,13 | 2,9717 | 0,251 |
| 8 | Kokdumala | XV-HР+XV-P | 0,170 | 0,31 | 0,15 | 2,2768 | 0,058 |
| 9 | Okkul | XV+XVa | 0,291 | 0,19 | 0,14 | 5,2083 | 0,030 |
| 10 | Arniyaz | XV-HР+XV-P | 0,108 | 0,37 | 0,12 | 5,2083 | 0,216 |
| 11 | Garmiston | XV-HР+XV-P | 0,161 | 0,35 | 0,08 | 2,8815 | 0,065 |
| 12 | Severny Shurtan 0 | XV-HР+XV-P | 0,187 | 0,25 | 0,10 | 4,9333 | 0,089 |
| 13 | Shurchi | XV | 0,314 | 0,49 | 0,12 | 8,1967 | 0,657 |
| 14 | Shurchi | XVI | 0,107 | 0,45 | 0,11 | 2,1313 | 0,075 |
| 15 | Akjar | XV | 0,600 | 0,10 | 0,20 | 3,7850 | 0,550 |
| 16 | Akjar | XVI | 0,368 | 0,28 | 0,07 | 3,9541 | 0,192 |
| 17 | South Kemachi | XV-HР+XV-P | 0,311 | 0,34 | 0,18 | 2,4906 | 0,156 |
| 18 | Jarkak | XV+XVI | 0,167 | 0,28 | 0,18 | 2,9061 | 0,086 |
| 19 | Jarchi | XV-HР+XV-P | 0,201 | 0,34 | 0,18 | 5,8892 | 0,047 |
| 20 | Podreef Kokdumala | XV-ПР | 0,678 | 0,28 | 0,16 | 2,7855 | 0,372 |
| 21 | Shakarbulak | XV-HР+XV-P | 0,309 | 0,20 | 0,18 | 3,0039 | 0,156 |

**TABLE 2.** Results of intermediate calculations for the formation flushing coefficient

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| № | Fields | Horizon |  |  | 2 |  |  | 2 |  |
| 1 | Kruk | XV-ПР+XV-P | 1,128 | 0,734 | 0,5388 | 0,406 | 0,173 | 0,0300 | 0,1270 |
| 2 | Western Yulduzas | XV+XVa | 0,905 | 0,511 | 0,2612 | 0,459 | 0,226 | 0,0511 | 0,1156 |
| 3 | Western Tashli | XVa | 0,162 | -0,232 | 0,0539 | 0,052 | -0,181 | 0,0328 | 0,0420 |
| 4 | Eastern Tashli | XVI | 0,998 | 0,604 | 0,3649 | 0,550 | 0,317 | 0,1005 | 0,1915 |
| 5 | Northern Urtabulak | XV-HР+XV-P | 0,369 | -0,025 | 0,0007 | 0,049 | -0,184 | 0,0339 | 0,0046 |
| 6 | Umid | XV-HР+XV-P | 0,396 | 0,002 | 0 | 0,377 | 0,144 | 0,0208 | 0,0003 |
| 7 | Karaktoy | XV+XVa | 0,348 | -0,046 | 0,0022 | 0,251 | 0,018 | 0,0004 | -0,0009 |
| 8 | Kokdumala | XV-HР+XV-P | 0,170 | -0,224 | 0,0502 | 0,058 | -0,175 | 0,0307 | 0,0392 |
| 9 | Okkul | XV+XVa | 0,291 | -0,103 | 0,0106 | 0,030 | -0,203 | 0,0412 | 0,0209 |
| 10 | Arniyaz | XV-HР+XV-P | 0,108 | -0,286 | 0,0818 | 0,216 | -0,017 | 0,0003 | 0,0049 |
| 11 | Garmiston | XV-HР+XV-P | 0,161 | -0,233 | 0,0543 | 0,065 | -0,168 | 0,0283 | 0,0392 |
| № | Fields | Horizon |  |  | 2 |  |  | 2 |  |
| 12 | Severny Shurtan 0 | XV-HР+XV-P | 0,187 | -0,207 | 0,0429 | 0,089 | -0,144 | 0,0208 | 0,0298 |
| 13 | Shurchi | XV | 0,314 | -0,080 | 0,0064 | 0,657 | 0,424 | 0,1798 | -0,0340 |
| 14 | Shurchi | XVI | 0,107 | -0,287 | 0,0824 | 0,075 | -0,158 | 0,0250 | 0,0454 |
| 15 | Akjar | XV | 0,600 | 0,206 | 0,0425 | 0,550 | 0,317 | 0,1005 | 0,0653 |
| 16 | Akjar | XVI | 0,368 | -0,026 | 0,0007 | 0,192 | -0,041 | 0,0017 | 0,0011 |
| 17 | South Kemachi | XV-HР+XV-P | 0,311 | -0,083 | 0,0069 | 0,156 | -0,077 | 0,0060 | 0,0064 |
| 18 | Jarkak | XV+XVI | 0,167 | -0,227 | 0,0516 | 0,086 | -0,147 | 0,0216 | 0,0334 |
| 19 | Jarchi | XV-HР+XV-P | 0,201 | -0,193 | 0,0373 | 0,047 | -0,186 | 0,0346 | 0,0359 |
| 20 | Podreef Kokdumala | XV-ПР | 0,678 | 0,284 | 0,0807 | 0,372 | 0,139 | 0,0194 | 0,0395 |
| 21 | Shakarbulak | XV-HР+XV-P | 0,309 | -0,085 | 0,0073 | 0,156 | -0,077 | 0,0060 | 0,0066 |

**TABLE 3.** Correlation matrix

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Factors and indicators | Correlation coefficient | | | | | Average values | Dispersion |
| Oil displacement coefficient by water | Flush coefficient | Water saturation coefficient | Porosity coefficient | Heterogeneity coefficient |
| Oil displacement coefficient by water | 1 | 0,9465 | -0,8062 | 0,2803 | -0,4668 | 0,233 | 0,1442 |
| Flush coefficient | 0,9465 | 1 | 0 | 0 | 0 | 0,394 | 0,2981 |
| Water saturation coefficient | -0,8062 | 0 | 1 | 0 | 0 | 0,280 | 0,0969 |
| Porosity coefficient | 0,2803 | 0 | 0 | 1 | 0 | 0,140 | 0,0360 |
| Heterogeneity coefficient | -0,4668 | 0 | 0 | 0 | 1 | 4,267 | 3,0775 |

Since the calculations were planned using the combination square method, then due to the neutralization of the mutual influence of factors, the coefficients of their pair correlation are zero. From Table 2 it follows that the greatest influence on the coefficient of oil displacement by water is exerted by the coefficient of formation flushing, as well as the initial water saturation of reservoirs, and to a much lesser extent by the porosity coefficient and the coefficient of heterogeneity.

**TABLE 4.** Correlation matrix for objects with reef carbonate reservoirs

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Factors and indicator | Correlation coefficient | | | | | Average values | Dispersion |
| Efficiency of oil displacement by water | Formation flushing coefficient | Water saturation  coefficient | Porosity coefficient | Heterogeneity  coefficient |
| Efficiency of oil displacement by water | 1 | 0,8244 | -0,3105 | 0,4277 | -0,1613 | 0,228 | 0,1923 |
| Formation flushing coefficient | 0,8244 | 1 | 0 | 0 | 0 | 0,458 | 0,3706 |
| Water saturation coefficient | -0,3105 | 0 | 1 | 0 | 0 | 0,260 | 0,0836 |
| Porosity coefficient | 0,4277 | 0 | 0 | 1 | 0 | 0,14 | 0,0264 |
| Heterogeneity coefficient | -0,1613 | 0 | 0 | 0 | 1 | 4,503 | 3,9686 |

Since different types of rocks are distinguished in the carbonate deposits of the Bukhara-Khiva region, we will consider the derivation of the regression equation for depression and reef deposits. Tables 4 and 5 show the values of the correlation coefficients, average values of the factors and standard deviations, respectively, for objects represented by reef and depression carbonate deposits.

From Table 4 it follows that in objects with reef deposits the greatest influence on the coefficient of oil displacement by water is exerted by the coefficient of formation flushing, and other factors (the coefficient of initial water saturation, the coefficient of porosity and the coefficient of heterogeneity) have a much lesser influence.

**TABLE 5.** Correlation matrix for objects with depression carbonate reservoirs

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Factors and indicator | Correlation coefficient | | | | | Average values | Dispersion |
| Efficiency of oil displacement by water | Formation flushing coefficient | Water saturation coefficient | Porosity coefficient | Heterogeneity  coefficient |
| Efficiency of oil displacement by water | 1 | 0,6491 | -0,1350 | 0,7477 | -0,4716 | 0,238 | 0,2149 |
| Formation flushing coefficient | 0,6491 | 1 | 0 | 0 | 0 | 0,324 | 0,1867 |
| Water saturation coefficient | -0,1350 | 0 | 1 | 0 | 0 | 0,300 | 0,1077 |
| Porosity coefficient | 0,7477 | 0 | 0 | 1 | 0 | 0,15 | 0,0424 |
| Heterogeneity coefficient | 0 | 0 | 0 | 0 | 1 | 4,007 | 1,8718 |

From Table 5 it follows that the greatest influence on the coefficient of oil displacement by water in objects represented by depression carbonate rocks is exerted by the coefficient of porosity and the coefficient of formation flushing and, to a much lesser extent, the coefficient of heterogeneity and the coefficient of initial water saturation.

We will present the derivation of the regression equation for the oil displacement coefficient by water for terrigenous rocks of the Bukhara-Khiva region, given in Table 6. In the calculations, according to the results of the information content assessment, the influence of six factors on the oil displacement coefficient by water (Kod) was studied: formation flushing coefficient (Vpor); permeability (K); mobility coefficient (Kmob); heterogeneity coefficient (S); initial water saturation coefficient. (Kvn); porosity coefficient (m).

Table 7 shows the values of the correlation coefficients, average values of the factors and standard deviations.

**TABLE 6.** Values of factors for terrigenous rocks

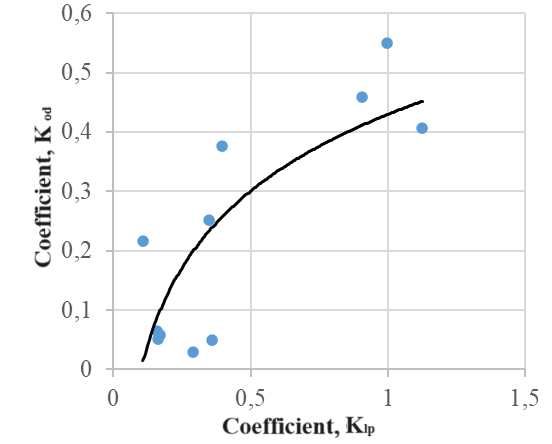
|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **№.** | Factors | | | | | | Coefficient of oil displacement by water, fractions of units |
| Coefficient of formation flushing, fractions of units | Coefficient of water saturation, fractions of units | Formation permeability,  mkm2 | Mobility coefficient, mkm2/mPa\*s | Heterogeneity coefficient, fractions of units | Porosity coefficient, fractions of units  . |
| 1 | 0,283 | 0,40 | 0,250 | 0,192 | 4,7824 | 0,23 | 0,155 |
| 2 | 0,352 | 0,34 | 0,287 | 0,233 | 2,6219 | 0,20 | 0,305 |
| 3 | 0,124 | 0,60 | 0,250 | 0,215 | 4,7824 | 0,13 | 0,073 |
| 4 | 0,812 | 0,48 | 0,013 | 0,021 | 8,1967 | 0,20 | 0,552 |
| 5 | 0,547 | 0,30 | 0,012 | 0,024 | 8,6805 | 0,16 | 0,476 |
| 6 | 0,756 | 0,44 | 0,242 | 0,027 | 2,7247 | 0,20 | 0,423 |
| 7 | 0,691 | 0,10 | 1,250 | 1,190 | 1,9814 | 0,16 | 0,465 |
| 8 | 0,829 | 0,30 | 0,280 | 0,179 | 2,6364 | 0,18 | 0,396 |

**TABLE 7.** Correlation matrix for objects with terrigenous reservoirs

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Factors and indicator | Correlation coefficient | | | | | | | | |
| Efficiency of oil  displacement by water | Liquid pumping  coefficient | Permeability | Mobility coefficient | Degree of heterogeneity | Initial water saturation  coefficient | Porosity coefficient | Average values | Dispersion |
| Efficiency of oil displacement by water | 1 | 0,8833 | 0,0965 | 0,0114 | -0,2767 | -0,0975 | 0,1764 | 0,356 | 0,1667 |
| Efficiency of liquid pumping | 0,8833 | 1 | 0 | 0 | 0 | 0 | 0 | 0,549 | 0,2676 |
| Permeability | 0,0965 | 0 | 1 | 0 | 0 | 0 | 0 | 0,323 | 0,3915 |
| Mobility coefficient | 0,0114 | 0 | 0 | 1 | 0 | 0 | 0 | 0,260 | 0,3866 |
| Degree of heterogeneity | -0,2767 | 0 | 0 | 0 | 1 | 0 | 0 | 4,5508 | 2,4004 |
| Efficiency of initial water saturation | -0,0975 | 0 | 0 | 0 | 0 | 1 | 0 | 0,37 | 0,1486 |
| Efficiency of porosity | 0,1764 | 0 | 0 | 0 | 0 | 0 | 1 | 0,18 | 0,0316 |

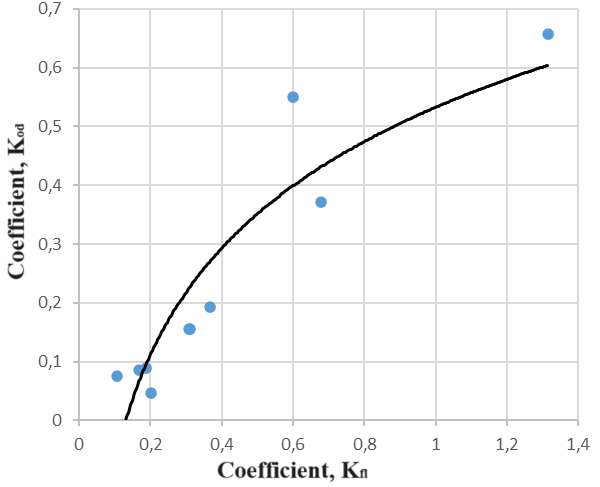
For all types of rocks, the value of the coefficient of oil displacement by water is mainly influenced by the coefficient of formation flushing. For carbonate rocks of reef and depression deposits of the Bukhara-Khiva region, the dependence of the displacement coefficient on the coefficient of formation flushing, with a high correlation coefficient, is described by an exponential dependence of the following type:

for carbonate rocks of reef deposits (Fig. 1)



**FIGURE 1.** Dependence of the oil displacement coefficient by water on the formation pumping coefficient for objects of the Bukhara-Khiva region, represented by reef carbonate deposits

Кod = 1,0167 (1-е-0,6037\* V), with a correlation coefficient of 0.830 and a standard error of 11.3%; for carbonate rocks with depression deposits (Fig. 2)



**FIGURE 2.** Dependence of the oil displacement coefficient by water on the formation flushing coefficient for objects of the Bukhara-Khiva region, represented by depression carbonate deposits

Кod = 1,0103 (0,901 –е-1,099\*V), with a correlation coefficient of 0.9486 and a standard error of 7.7%; the formation flushing coefficient is a factor that changes during the development of deposits, as a result of which the value of the oil displacement coefficient by water cannot be taken as a constant when designing field development.

**CONCLUSION**

Models for estimating the oil displacement coefficient for carbonate rocks of the Bukhara-Khiva region represented by reef and depression facies have been created. It has been shown that for both types of carbonate rocks, the formation flushing coefficient has the main influence on the value of the oil displacement coefficient by water.

To determine the value of the oil displacement coefficient by water for the Bukhara-Khiva region objects, it is recommended to use the obtained multi-member models, since they describe the process more reasonably than the previously proposed single-factor dependencies.

It is shown that objects of study due to rock fracturing, high geological heterogeneity and small effective oil-saturated thickness do not meet the criteria of effective application of physical and chemical methods of increasing oil recovery coefficient. At the same time, the decrease in the oil saturation coefficient during development greatly limits the prospects for the effective use of physical and chemical methods in the late stages of oil deposit exploitation.

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