Grouping of Objects Using a Limited Number of Parameters Characterizing Geological and Physical Properties of Layers

Akhmetov R.T.
Department of Oil and Gas Field Exploration and Development
Ufa State Petroleum Technological University,
Branch of the University in the City of Oktyabrsky
Oktyabrsky, Republic of Bashkortostan, Russia
vsh@of.ugntu.ru

Mukhametshin V.V.
Department of Oil and Gas &Oil Field Development and Operation
Ufa State Petroleum Technological University
Ufa, Republic of Bashkortostan, Russia
vv@of.ugntu.ru

Kuleshova L.S.
Department of Oil and Gas Field Exploration and Development
Ufa State Petroleum Technological University,
Branch of the University in the City of Oktyabrsky
Oktyabrsky, Republic of Bashkortostan, Russia
markl212@mail.ru

***Abstract* — For grouping objects of Western Siberia it is proposed to use the parameters characterizing the degree of influence on the displacement factor of radial *microinhomogeneities* and *hydrofobisation* of pore channels of the productive strata. These parameters are obtained from the analytical expression for the displacement factor as a linear combination of factors associated with individual components of residual oil saturation: effective porosity and volumetrical residual water saturation. The values of the parameters are determined by statistical processing of laboratory data of core samples of the reservoir at the stage of *reserve calculation*. a standart crossplot are build with help of informantion about groups of objects in exploitation. The location of the point corresponding to the designed object, the nearest group number on the standart crossplot determine the desired group of the new object.**

Keywords — displacement factor; hydrofobisation; reservoir recovery rate; grouping of objects.

I. Introduction

Grouping is the allocation of homogeneous groups of objects on the general set of features (parameters).

Grouping allows you to solve a number of the most important tasks of oil-field geology and exploitation: to assess the similarities and differences between the productive strata in the process of object isolation of exploitation, to conduct a study of the exploitation systems, specify the measures for control and regulation and so on [1-9].

The effective solution of various problems of analysis, design, control and regulation of oil field exploitation systems is largely determined by the availability of high-quality sufficient information about the productive strata and the processes occurring in it. Obtaining this information becomes possible after the hydrodynamic and laboratory studies, as well as on the basis of studying the history of exploitation. Based on this, the requirements for the selection of objects of study should be:

- the object is in exploitation for a long time and there is sufficient for the solution of tasks field-geological and material
- the object is developed quite tightly by a system of wellsites for various purposes;
- a sufficient number of hydrodynamic, geophysical and laboratory studies have been carried out at the facility to solve the tasks.

The object of research is understood as the object of expoitation, that is, one or more productive layers of the field, allocated on the basis of geological and technical, and economic considerations for developing and using of a single wellsites system. The objects of research (development) are both separate areas of the field, contoured recharge well, individual domes, uplifts, and productive layers of the fields as a whole.

To successfully solve the problem associated with the grouping, objects that are in exploitation for a short time can be used, dreveloped insufficiently densely by the system of producing wells and operated by single wells, but their geological structure has been studied sufficiently fully, on the basis of data obtained from wells developed to other productive horizons. When selecting such objects, it is desirable to take into account the pressure communication between the individual layers.

The complex of parameters used for grouping objects includes: filtration-volumetric characteristics, micro-macroinhomogeneity, thickness characteristics and position of productive strata, as well as physical and chemical characteristics of formation fluid (more than 10 parameters).

In the conditions of oil reservoir in terrigenous reservoirs of Western Siberia, characterized by wide intervals of changes in the storage condition, geological-physical and physico-chemical properties of the layers and their saturating fluids, of paramount importance is the operation of identification (grouping), i.e. the allocation of relatively free groups of objects using the following parameters: effective water-saturated thickness, factor of porosity (determined according to geophysical and laboratory studies), oil content, permeability variations, viscosity, relative viscosity, density of formation oil, depth of burial, formation gas-oil ratio, original reservoir pressure and temperature. The choice of these parameters is due, first of all, to the need to create an algorithm for grouping deposits, allowing already at the stage of exit from exploration and preparation of the first design documents for exploitation (when these parameters are determined accurately enough) to refer the new object to any of the known groups of objects under exploitation.

However, the most interesting algorithms are grouping by a limited number of parameters, as they allow already at the stage of exit from the exploration and preparation of design documents for the exploitation of a new object to refer to any of the known groups of objects-analogues in development. The use of the experience of the fields developed for a long time, in the conditions of new facilities, will allow making informed technological decisions in the preparation of development projects, to identify ways and means of improving the efficiency of exploitation, correctly and reasonably monitor and regulate the exploitation process.

Obviously, the grouping of field by a limited number of features is possible only with the use of generalized parameters that integrally characterize this object.

In other words, the generalized parameters should be practically unchanged for a given specific field and uniquely characterize this production facility.

II. METHODS AND MATERIALS

In this article, the parameters of the mathematical model of the relationship of the oil displacement factor with filtration-volumetric characteristics for a number of groups of objects of West Siberian oil and gas province.

In this case, we used the results of laboratory studies of core samples.

The possibility of grouping objects using a limited number of parameters according to the results of statistical processing is shown.

III. RESULTS AND DISCUSSIONS

In our opinion, the generalized parameters can be identified by analyzing the results of laboratory studies of fluid filtration on core samples of a particular field: capillarimetric studies or experimental studies of the process of oil displacement by water from oil-saturated samples.

It should be noted that capillarimetry simulates the processes of fluid motion in the formation of oil and gas fields, and when oil is displaced by water from the core samples – the process of oil field exploitation. As a result, the use of the results of experimental studies of oil displacement by water in the grouping of objects is more preferable.

Thus, it is proposed to use the parameters of the mathematical model of the interconnexion the oil displacement factor by water and the filtration-volumetric characteristics of the core samples of the formations of this object as generalized indicators.

As signs at recognition of objects it is offered to use the coefficients characterizing degree of influence of complex parameters (effective porosity, volume humidity) on size of oil displacement factor by water.

In the case of water-saturated formation, water moistens the surface of the pore channels and displaces oil into pores of large and medium size, as the action of capillary forces in this case contributes to a more complete displacement of oil.

As a result of displacement of water in a porous medium remains 20-45% of residual oil, which is a separate globules (droplets) of oil, blocked in the pores of the reservoir.

[10]. Studies show that the amount of blocked (trapped) oil is determined by the ratio of pore sizes and interporous constrictions. Because of this, the quantitative assessment of the content of trapped residual oil in the rock is possible by using a "dumbbell" model of the void space of granular reservoirs [10].

Consider the "dumbbell" model in more detail.

In this case, each pore channel is represented by an alternation of cylindrical capillaries of large (S_b) and small (S_m) sections. The capillaries large cross-section of the model pore, and between pores of small cross section constriction.

Due to the electro-hydrodynamical analogy in the quantitative assessment of the interconnexion the filtration and storage capacitiy of rocks, the main role is played by electrical survey techniques.

In this case, we will use the following electrical parameters: the porosity parameter (R_p) and the saturation parameter (P_s). The first parameter characterizes the structure of the void space, completely water-saturated, and the second – partially water-saturated rock.

Each channel of the "dumbbell" model is characterized by the following equivalent (effective) sections:

S_m – cross-section microcapillaries (interporous contractions);

S_b – cross-section microcapillaries (porous);

S_e – equivalent capacitive section, determined by the porous factor;

S_s – equivalent electric section, determined by

formation resistivity factor and oil-and-gas saturation;

S_f – equivalent filtration section, determined by absolute permeability index.

Note that all the equivalent sections for the "dumbbell" model, as close as possible to the real mountain rock, differ from each other, but we can get ratios between them. With a known value of one of the effective sections (for example, electrical), these relations allow us to calculate all equivalent (effective) sections.

Let *p* be the total fraction of microcapillaries (interporous contractions) on a unit length of the pore channel. Then

1-p is the total share of macrocapillaries (pores) on a unit length of the pore channel.

If linear fractions of micro and macro capillaries are known, then the following equations can be made:

$$[p/S_{\mathrm{m}} + (1-p)/S_{\mathrm{b}}]\cdot\frac{1}{N_{\mathrm{F}}} = \frac{1}{S_{\mathrm{s}}N_{\mathrm{F}}} = P_{\mathrm{s}},$$

$$[p/S_{\mathrm{m}} + (1-p)\cdot S_{\mathrm{b}}]\cdot N_{\mathrm{F}} = S_{\mathrm{e}}\cdot N_{\mathrm{F}} = K_{\mathrm{P}}.$$

where K_P is the coefficient of porosity; N_F - areal density channels

We multiply both parts of these equations. At the same time we get:

$$p\cdot(1-p)\cdot\frac{S_{\mathrm{m}}}{S_{\mathrm{b}}} + p(1-p)\cdot\frac{S_{\mathrm{b}}}{S_{\mathrm{m}}} + p^2 + (1-p)^2 = P_{\mathrm{s}}K_{\mathrm{p}}.$$ This equation is converted to the following form:

$$1 + p(1-p)\cdot\left[\frac{S_{\mathrm{b}}}{S_{\mathrm{m}}} + \frac{S_{\mathrm{m}}}{S_{\mathrm{b}}} - 2\right] = P_{\mathrm{s}}K_{\mathrm{P}}.$$

From here we can express:

$$\frac{S_{\mathrm{P}}}{S_{\mathrm{K}}} \approx 1 + \frac{P_{\mathrm{s}}K_{\mathrm{P}} - 1}{p(1-p)}.$$

Thus, we have obtained the expression for the ratio of cross sections of pores (S_b) and interporous tubules (S_m).

Obviously, fluid in the reservoirs occurs in the effective part of the void space. Therefore, the effective porosity should be used in the formula for the ratio of cross sections of pores and interporous contractions.

In accordance with the dumbbell model, the heterogeneity of the void space of the productive strata along the filtration line is determined, first of all, by the effective porosity of the reservoir. Therefore, we have:

$$\mathrm{W} = \mathrm{a} + \mathrm{b}\cdot\mathrm{K}_{p,e}^{-1}, \qquad (1)$$

where *a* and *b* are fixed indexes.

According to modern concepts, oil and gas reservoirs initially are hydrophilic before oil enters the reservoir.

In the interaction of surface-active components - resins and asphaltenes, after the oil enters the reservoir, the porous channels partially hydrophobize. At the same time, part of the surface of the pore space still remains covered with a film of residual (relic) water, and in the other part the formation of boundary layers of oil occurs, the viscosity of which considerably exceeds the viscosity of oil in the free volume

According to many researchers, the hydrofobisation of collectors in Western Siberia is directly related to their clay content [11].

The clay fraction is represented by such active adsorbents as montmorillonite, hydromica, chlorite, and their mixed-layer According to the authors, lining the walls of the pore channels, clay minerals adsorb water and hydrocarbons, forming adsorption layers of various thicknesses. Adsorbed hydrocarbons are capable of adhesion of other hydrocarbons that are filtered through the pore channels, which leads to the formation of extended hydrophobic regions.

Our studies show that in the conditions of Western Siberia, each mineralogical type of reservoir is determined by the specific value of the volume residual water saturation K_pK_{vo}.

Thus, the volume residual water saturation on the one hand determines the degree of dispersion (clay content) of the reservoir, and on the other hand is a measure of the hydrophobization of the reservoir.

In the reservoirs of Western Siberia, when oil is displaced by water from the void space of the productive strata, the residual oil is composed of two components: capillary-pinched and adsorbed on the surface of clay aggregates as separate droplets and films

The content of capillary-clamped residual oil can be estimated from the value of the effective porosity of the reservoir *($K_{p.e}$)*, since it characterizes the ratio of pore sizes and interpore contractions [12].

The content of hydrocarbons adsorbed on the active pore surface depends on the clay content and activity of the clay material. The fraction of adsorbed residual oil can be estimated in terms of the volume residual water saturation K_pK_{vo}.

Based on these considerations, we propose to use a linear combination of parameters associated with individual components of residual oil saturation to calculate the displacement factor:

$$\mathrm{K}_{dis} = \alpha + \beta\cdot\mathrm{K}_{p,e}^{-1} + \gamma\cdot(\mathrm{K}_p\cdot\mathrm{K}_{vo}), \qquad (2)$$

α, β and γ are fixed coefficients for a given productive formation.

The proposed method of predicting the displacement coefficient is as follows.

Under laboratory conditions, open porosity, residual water saturation, residual oil saturation are determined on the core samples from this reservoir.

By statistical processing of laboratory data, a formula for the oil displacement coefficient by water is obtained, which is a linear combination of parameters taking into account the share of trapped oil and field hydrofobisation . In this case, the share of trapped oil is determined by the effective porosity and the degree of hydrofobisation by the volume residual water saturation of the reservoir.

Further, during the exploitationof the field, the values of porosity and residual water saturation necessary for the prediction of the displacement factor are determined according to the field geophysical studies of producing wells. At the same time, it is possible to predict the displacement factor in each layer of intersections both in the section and in the area of the field immediately after the completion of developing and geophysical studies of wells.

The analysis of the obtained equations of dependence of the displacement factor on the complex parameters (effective porosity, volumetric water saturation) showed that in the conditions of different groups of objects of West Siberian oil and gas province. [4] the values of the coefficients are different, which once again indicates the need for a differentiated approach to managing the exploitation of these objects.

The table shows the values of the constant coefficients of the equations of the form (1) for groups of objects West Siberian oil and gas province and in the figure – the distribution of coefficients for different groups of objects (reference crossplot). The results were obtained from laboratory studies. You can see that each group of objects occupies a certain and limited area in this coordinate system

It should be noted that the dependences $K_{выт} = f(K_{п.э}^{-1},\ K_{п}K_{во})$, obtained for each object are stochastic, although they have a fairly high correlation coefficient (0.85-0.9).

TABLE I. VALUES OF CONSTANT COEFFICIENTS DEPENDENCIES ON GROUPS OF OBJECTS WEST SIBERIAN OIL AND GAS PROVINCE

Object group number	α	β	γ
1	0,775	-0,02	-1
3	0,718	-0,0333	1,018
4	0,777	-0,0088	-2,18
5	0,945	-0,024	-30,8
6	0,705	-0,024	-3,08
7	01,035	-0,005	-6,58
9	0,818	-0,027	-1,4
12	1,044	-0,03283	-5,10798
13	0,996	-0,03527	-1,95504
14	0,561	-0,02508	-0,03775

The standard crossplot is built according to the groups of objects under exploitation.

Further, by the location of the point corresponding to the designed object by the nearest group number on the standard crossplot, determine the desired group of the new object.

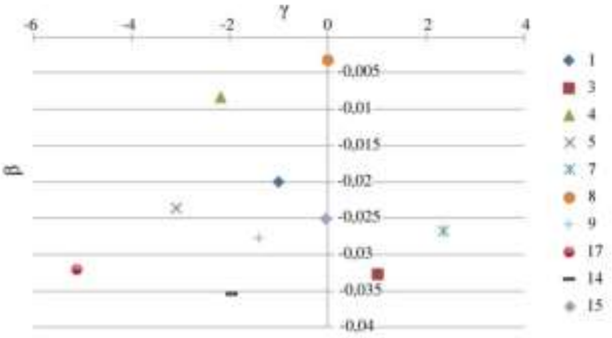

Fig. 1. Distribution of coefficients β and γ for different groups of objects (standard crossplot).

The presented results are extremely important when entering the fields into exploitation, when choosing a exploitation strategy, monitoring and management.

IV. CONCLUSION

The possibility of using a mathematical model of predicting the factor of displacement of oil by water in the grouping of production facilities is shown.

The obtained results are of particular importance in the selection of methods to improve oil recovery and evaluation of their effectiveness.

References

[1] J.E. Hodgin, D.R. Harrell, "The Selection, Application, and Misapplication of Reservoir Analogs for the Estimation of Petroleum Reserves", 2006 [SPE Annual Technical Conference and Exhibition]. DOI: 10.2118/102505-MS

[2] N.Sh. Khayredinov, A.M. Popov, V.Sh. Mukhametshin, "Increasing the flooding efficiency of poor-producing oil deposits in carbonate collectors", Oil industry, no. 9, pp. 18–20, 1992.

[3] D.K. Larue, Y. Yue, "How stratigraphy influences oil recovery: a comparative reservoir database study", The Leading Edge, vol. 22, no. 4, pp. 332–339, 2003.

[4] V.Sh. Mukhametshin, "Dependence of crude-oil recovery on the well spacing density during development of low-producing carbonate deposits", Oil Industry, no. 12, pp. 26–29, 1989.

[5] W.L. Leffler, R. Pattarozzi, G. Sterling, Deepwater Petroleum Exploration & Production: A Nontechnical Guide. PennWell, 2003, 166 p.

[6] V.V. Mukhametshin, "Rationale for trends in increasing oil reserves depletion in Western Siberia cretaceous deposits based on targets identification", Bulletin of the Tomsk Polytechnic University, Geo Assets Engineering, vol. 329, no. 5, pp. 117–124, 2018.

[7] J. Allan, Sun S. Qing, "Controls on Recovery Factor in Fractured Reservoirs: Lessons Learned from 100 Fractured Fields", pp, 1–18, 2003 [SPE Annual Technical Conference and Exhibition]. DOI: 10.2118/84590-MS

[8] V.V. Sergeev, N.G. Belenkova, Yu.V. Zeigman, V.Sh. Mukhametshin, "Physical properties of emulsion systems with SiO_2 nanoparticles", Nanotechnologies in Construction, vol. 9, no. 6, pp. 37–64, 2017. DOI: 10.15828/2075-8545-2017-9-6-37-64

[9] D. Beliveau, "Waterflooding Viscous Oil Reservoirs," pp. 1–13, 2008 [SPE Indian Oil and Gas Technical Conference and Exhibition]. DOI: 10.2118/113132-MS

[10] R.T. Akhmetov, V.V. Mukhametshin, “Range of application of the Brooks-Corey model for approximation of capillary curves in reservoirs of Western Siberia”, Advances in Engineering Research (AER), vol. 157, pp. 5–8, 2018. DOI: 10.2991/aime-18.2018.2 [Proceedings of the International Conference “Actual Issues of Mechanical Engineering” (AIME 2018)].

[11] N.N. Mikhailov, L.S. Sechina, K.A. Motorova, “Role of clay minerals in formation of the adsorption-connected oil in rock-collectors of hydrocarbonic raw materials”, Georesources, geoenergetics, geopolitics, no. 1 (5), pp. 51, 2012.

[12] R.T. Akhmetov, A.V. Andreev, V.V. Mukhametshin, “Residual oil saturation and the displacement factor prediction methodology based on geophysical studies data to evaluate efficiency of nanotechnologies application”, Nanotechnologies in Construction, vol. 9, no. 5, pp. 116–133, 2017. DOI: 10.15828/2075-8545-2017-9-5-116-133.

[13] R.R. Kadyrov, L.S. Kuleshova, I.G. Fattakhov, “Technologies and technical devices for annual regulated flooding of a productive strata”, Advances in Engineering Research (AER), vol. 157, pp. 232–235, 2018. DOI: 10.2991/aime-18.2018.45 [International conference “Actual issues of mechanical engineering” (AIME 2018)].