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Improving efficiency of oil recovery and finding a source of watering in multi-zone deposits by geochemical methods of research

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Abstract. One of the strategic ways in the development of multilayer fields is to identify the source of water inflow into the well production and, as a result, to eliminate it with subsequent optimization of the production of non-watered formations. A method for assessing the degree of water cut in formations based on the quantitative characteristics of the composition of the produced water is proposed in this article. The study of a wide collection of produced water samples made it possible to trace the change in its geochemical composition depending on the age of formation of the reservoir in the Volga-Ural region.The microelements and macro element composition of water, as well as its isotopic composition were investigated. The water of different layers differs in some of the elements, which are called «key elements». Using the methods of mathematical statistics at 2 reservoir objects operated by a common filter, the incoming water was divided into fractions depending on the geochemical composition. It is shown which of the layers has more water out. The feasibility of carrying out these geochemical studies was confirmed by blocking one of the production wells operating in 2 layers, the most watered interval according to geochemical studies, as a result of which the water cut of the well production decreased from an average of 75% to 4% and is observed for several months, the oil production rate increased from 1–2 t/day to 2.5–3 t/day and remains at a constant level.

Keywords: chemical composition of water; isotope study; geochemistry of formation systems; improvement of oil field development; hydrogeology of petroleum engineering

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Introduction

Formation waters are essential part of oil fields. The geochemical characterization of formation waters is important for studying the diagenetic history of sedimentary basins (Demir, 1995), as well as for the analyzing reservoirs in order to define applicability of improved oil recovery methods, have been repeatedly noted in works (Poroshin, Mulyak, 2004, Fedorova Shits, 2011; etc.). This information can also be used for practical purposes, for the prompt solution of challenges emerging during the field development. Water interacts with the reservoir rocks, formation fluids and as the most mobile and sensitive to changes system, contains indirect information about in-situ processes – sorption and desorption, diffusion, ion exchange, hydration and dehydration, dissolution and lixiviation, salt sedimentation, osmotic, filtration and other physical and chemical phenomena hidden from the eyes (Fedorova, Shits, 2019).

Most of the fields in Tatarstan Republic are multilayered with oil deposits often overlapping in plan. Hence, the specificity of oil production from such fields are the close location of oil-bearing formations and the grouping of formations with similar characteristics into a single development object. Oil is produced from each of them simultaneously.

The best way to ensure maximum oil recovery in the process of multilayered field development producing oil from several reservoirs simultaneously by single grid of wells are to keep constant producing rates and provide uniform advancement of displaced oil drainage boundaries in each of reservoirs. However, in reality, due to the reservoirs heterogeneity, the oil production from the reservoirs is carried out unevenly (Kosarev, 2009).

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Identification of the most flooding formations, especially in the complex oil fields structure conditions, is possible on the basis of modern technologies (Poroshin, Mulyak, 2004). They have high diagnostic efficiency and are easy to use and not expensive in their cost. The effectiveness of these technologies and their reliability were determined on the petrophysical and hydrodynamic characteristics studying results. Oil reservoirs, represented by multilayered reservoirs with heterogeneous permeability, were studied (Gilmanova et al., 2012).

One of the modern technologies is geochemical monitoring of reservoir systems. The purpose of these studies is to find out the main source of water inflow into the well production i.e. is to determine the most flooding objects in the development process. In order to study the hydrochemical conditions formed in the reservoir, 20 samples of formation waters of the Alekseevskoye field (Tatarstan Republic) were taken. The chemical analysis of waters was carried out in the laboratories of Kazan Federal University (Kazan). A method for processing the obtained features in the geochemical composition has been developed. This method takes into account wells selecting stage and the choice of mathematical statistics methods and the development of special algorithms.

The Alekseevskoye oil field (Figure 1) has eight productive horizons along the geological cross-section, which are subdivided into formations and sub-formations. The productive formations are the Devonian and Lower Carboniferous terrigenous and carbonate reservoirs. This article presents studies of the water composition of the Bobrikian terrigenous horizon, the Kizelian carbonate horizon, the Zavolzhian carbonate horizon and the Pashyian terrigenous horizon.

Fig. 1. Overview map of the location of the studied field

Research methods and study techniques

Comprehensive studies of the associated formation water samples were conducted using Inductively Coupled Plasma mass spectrometers. Delta V Plus isotope mass spectrometer (ThermoFisher Scientific, Germany) with a GasBench II consol in a constant flow mode is used to determine the hydrogen isotopic composition of water samples. iCAP Qc Inductively Coupled Plasma mass spectrometer (Thermo Fisher Scientific, Germany) is used to determine the elemental composition of water.

Mass-spectrometric methods, which are both high-precision and highly sensitive, make it possible to analyze both the composition of a sample itself and the composition of admixtures in it. The sensitivity of mass spectrometry to admixtures exceeds the sensitivity of other analytical methods (Gall, Kurochkin, 2002).

Such outstanding scientists as Vernadsky V.I., Zhirmunsky A.M., Kozyrev A.A., Lange O.K., Lebedev A.F., Lichkov B.L., Meintser O.E., Slavyanov N.N. et al. were engaged in the development of natural groundwaters classifications. All proposed classifications were based on various geochemical and hydrodynamic criteria, waters occurrence and origin conditions. The classification of groundwaters proposed by V.A. Sulin (Sulin, 1935) is widely used. According to this classification, waters are divided into four types: 1) sodium-sulfate; 2) sodium-bicarbonate; 3) magnesium-chloride; 4) calcium-chloride. The ratio of individual ions quantities (in milligram-equivalents) established by laboratory analysis makes it possible to determine water type. However, according to these parameters, it is not always possible to differentiate water from different layers clearly.

Methods based on the groundwater chemical composition study have the disadvantage that the nature of water is determined by the content of certain chemical compounds (anions, cations). Groundwater mineralization or saturation with various salts and elements occurs in the process of their interaction with rocks, oil and gas under the influence of high temperatures, catalytic properties of rocks and microbiological processes (Geology Reference Manual). The isotopic composition of water is interesting because, in addition to hydrogen with an atomic weight of 1 (protium) and oxygen with an atomic weight of 16, natural water molecules include hydrogen with an atomic weight of 2 (deuterium, D) and oxygen with an atomic weight of 18 and 17 (Kartsev, 1972). There are certain differences in the isotopic composition of natural waters, depending on the genesis and source of the incoming water.

The algorithm of the geochemical method for determining the well production flooding source, developed in this work, include following steps:

1) Wells, which characterized by producing oil from 1 horizon separately, absence of casing integrity damage and interstratal behind-the-casing flows, are investigated. Such wells are the reference for the "clean" samples selection of associated formation water.

2) The associated produced waters composition and their correlation with the developed formations

properties depending on age are detailed analyzed.

3) The characteristic features of formation waters from development objects are determined (if it is possible, detailed to formations).

4) Wells producing oil from 2 reservoirs simultaneously are investigated.

5) The results obtained during the research are processed by methods of mathematical statistics. Special algorithms are developed, depending on the field and the objectives of the research. The most flooded reservoir found out by calculating the water inflow fraction.

Results

Collection of water samples from 17 reference wells was studied. As a result, distinctive features in the isotopic and elemental composition of water corresponding to different formations were identified (Table 1). Waters are surely divided according to the content of Manganese (Figure 2) and Deuterium (Figure 3). These 2 characteristics are selected as the main markers, allowing to classify waters of the different ages in the studied oil field.

In general, about 50 elements of water samples are analyzed. This database is processed by mathematical statistics methods, which allows to select unique elements – markers by which the water of different formations can be divided.

Statistical modeling

It is assumed that the distribution of each of the training set samples coincides with the distribution of the test sample X, Y. Each sample is independent in the probabilistic sense from the others. For the characteristic m at a pure concentration of the component k, is assumed a normal distribution with the average $b_{m,k}$ and dispersion σ_m^2:

$$x_m | y_k = 1 \sim N(b_{m,k}, \sigma_m^2), \quad (1)$$

that is, the conditional distribution of x_m for a fixed vector Y, where the kth component is equal to one (hence, all the others are equal to zero). Further, all elements of the vector X are assumed to be independent from each other.

It is natural to assume that when the components are mixed, the observed characteristic x_m has a normal distribution with proportionally mixed means of each of the components:

$$x_m | Y \sim N(\sum_{k=1}^{K} b_{m,k} y_k, \sigma_m^2). \quad (2)$$

No.	Horizons	Number of reference wells	Mean, Mn, ppm	Mean, δD ‰	Mean, Fe, ppm
1	Bobrikovian C1bb	5	1657.9	-30.57	2210.3
2	Kizelovsky C1kz	4	188.2	-23,16	58.8
3	Zavolzhsky D3zv	5	67.3	-25.16	0
4	Pashiysky D3psh	3	12532.1	-1.81	166181.8

Table 1. Features of the water composition of reference wells

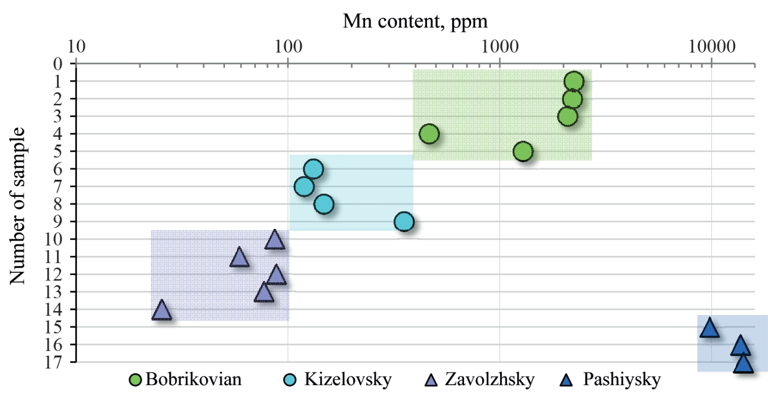

Fig. 2. Manganese content in reference wells

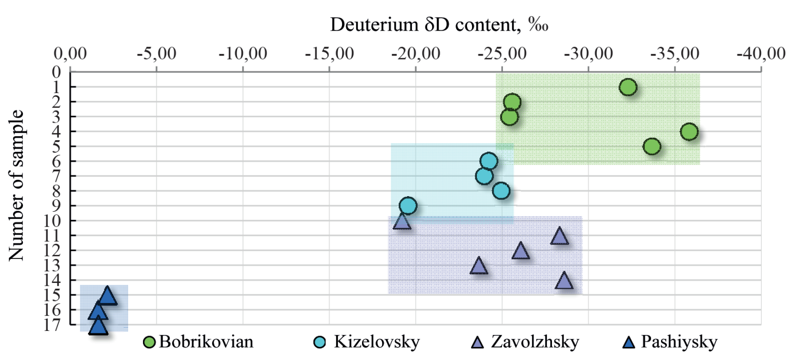

Fig. 3. Deuterium content in reference wells

If we denote

$$B=\begin{bmatrix} b_{1,1} & \cdots & b_{1,K} \\ \vdots & \ddots & \vdots \\ b_{M,1} & \cdots & b_{M,K} \end{bmatrix},\ S=\begin{bmatrix} \sigma_1^2 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \sigma_M^2 \end{bmatrix}, \quad (3)$$

then the vector X, provided that the content of the components Y is known, will have a multivariate normal distribution:

$$X|Y \sim N(BY, S). \quad (4)$$

To check mixture presence in the well, a statistical verification task is posed to test the corresponding hypothesis. Once it is decided that a mixture is observed, the proportion of the mixture can be estimated based on the maximum reliability method.

Application results

Table 2 shows the values for B, S obtained from the available data. The "Mean" column contains the matrix B, the "Mean root square deviation" column contains the values $\sigma_1 \ldots \sigma_M$. Only those characteristics are given that were used for the analysis. Other characteristics were excluded for one of the following reasons: a large amount of missing data (the mean for some classes cannot be estimated due to the incompleteness of the rank of the matrix of explicative variables), data abnormality (with too low reliability of the Box-Cox transformations).

As a result of the algorithm training and the fractions calculating, the following distribution of fluids over the formations is obtained (Table 3):

1) well 6526: 44% of water from the Bobrikian reservoirs, 56% from the Zavolzhian;

2) well 22: 33% of water from the Kizelian reservoirs, 67% from the Zavolzhian;

3) well 234: 72% of water from Bobrikian reservoirs, 28% from Kizelian.

Thus, the water cut sources for 3 wells were found. In order to confirm the obtained calculations, the most flooded Zavolzhian formations at well No. 6526, characterized by an average water cut is about 75%, was switched off.

Number of sample	Horizon	C1bb	C1kz	D3zv	D3psh
1	C1bb	1	0	0	0
2	C1bb	1	0	0	0
3	C1bb	1	0	0	0
4	C1bb	1	0	0	0
5	C1bb	1	0	0	0
6	C1kz	0	1	0	0
7	C1kz	0	1	0	0
8	C1kz	0	1	0	0
9	C1kz	0	1	0	0
10	D3zv	0	0	1	0
11	D3zv	0	0	1	0
12	D3zv	0	0	1	0
13	D3zv	0	0	1	0
14	D3zv	0	0	1	0
15	D3psh	0	0	0	1
16	D3psh	0	0	0	1
17	D3psh	0	0	0	1
6526	C1kz+D3zv	0	0.44	0.56	0
22	C1kz+D3zv	0	0.33	0.67	0
234	C1bb+C1kz	0.72	0.28	0	0

Table 3. Results of the algorithm

As a result of the Zavolzhian horizon shutting off, the average production rate increased and remained at a constant level (Figure 4), while the water cut decreased significantly – to values less than 10% and remained this low level for several months (Figure 5).

Conclusion

As a result of the associated formation water component composition studies, characteristic markers of the Bobrikian, Kizelian, Zavolzhian and Pashyian waters were established both for isotopic and microcomponent composition.

The waters differ in composition. In addition, the Pashyian horizon is unique and has a special component

Characteristics	Mean				Mean Root Square Deviation	Importance
	C1bb	C1kz	D3zv	D3psh		
δ18O.(VSMOW),.‰	-5.95	-6.162	-5.476	-9.33	1.572	2.498
δD.(VSMOW),.‰	-32.31	-24.037	-26.069	-1.808	4.126	20.801
Li	6063.08	8750.227	8469.246	5890.519	1212.699	3.167
Na	1E+08	94221489	90250000	86796559	5974269	1.837
Mg	5154141	5690341	4796676	4796676	1172667	0.259
Al	2704.816	1223.043	3633.776	3331.83	2296.753	0.436
K	1427690	1837801	1591735	1263645	153440.7	5.096
Ca	726977.7	902092.6	894762.5	1704409	103695.2	35.859
Mn	1294.766	-261.953	139.248	5037.828	4028.572	0.719
Rb	721.327	969.756	928.604	1170.38	123.714	4.429
Sr	299640.2	353482.8	299690.4	385818.5	94326.33	0.406
Cs	12.218	13.946	19.639	38.514	4.223	16.275
Ba	4606.002	589.597	-270.756	42010.76	47712.4	0.362
Alkali metals	1.01E+08	96069023.93	91851152.49	88067303.41	6319098	1.499
Alkaline-earth metals	6185364.902	6946505.997	5990858.144	6928914.26	1171331	0.428

Table 2. Results of choosing averages for water along the horizons

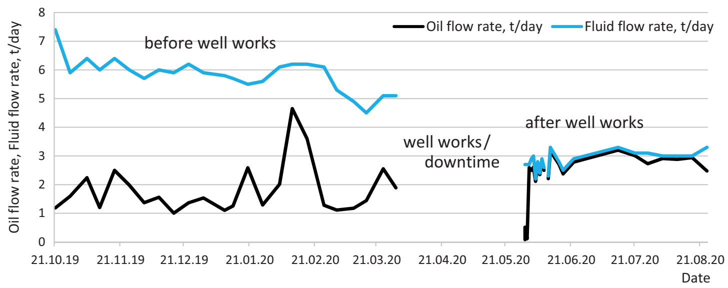

Fig. 4. Dynamics of fluid production in the well. 6526 before/after shutting-off the Zavolzhsky horizon according to the conclusion of geochemical analysis of fluids

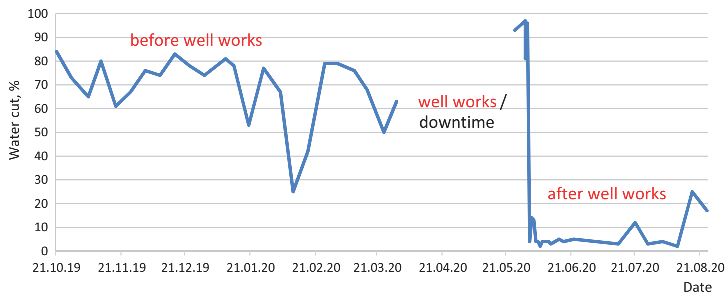

Fig. 5. Dynamics of water cut in the well 6526 before/after shutting-off the Zavolzhsky horizon according to the conclusion of geochemical analysis of fluids

composition of water (enriched with the heavy isotope of hydrogen and the increased content of manganese).

Characteristic features of each formation can be established. After that it seems possible to determine the relative water flow rates for wells producing oil from two reservoirs simultaneously. Modern methods of mathematical statistics are applied for that. All measured components in water composition are taken into account and the brightest and most representative samples are selected. The separation occurs on the basis of these components.

The geochemical monitoring technique was successfully confirmed by shutting off the most flooded formation. This led to a significant decrease in the well water cut percentage, an increase in production rate: water cut decreased from 75% to 4–20%, oil flow rate increased from 1–2 tons/day to 2.5–3.0 tons/day.

The proposed approach can be used in the development of other multilayered oil fields. Advantages of this approach are its low cost, the ability to conduct research without well shutoff, as well as the ability to promptly make decisions on the watered formations.

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