Wettability and formation conditions of reservoirs

A M Malyarenko¹, V A Bogdan², Yu A Kotenev³, V Sh Mukhametshin⁵, V G Umetbaev⁴

¹PJSC «Bashneftegeofizika», 13, Lenin Avenue, Ufa, Republic of Bashkortostan, 450077, Russia
²JSC NPF «Geophysics», 2, Komsomolskaya avenue, Ufa, Republic of Bashkortostan, 450005, Russia
³State autonomous scientific institution “Institute of strategic research of the Republic of Bashkortostan”, 129/3, October avenue, Ufa, Republic of Bashkortostan, 450075, Russia
⁴Ufa State Petroleum Technological University, 1, Kosmonavtov St., Ufa, Republic of Bashkortostan, 450062, Russia
⁵Ufa State Petroleum Technological University, Branch of the University in the City of Oktyabrskii, 54a, Devonskaia St., Oktyabrskaja, Republic of Bashkortostan, 452607, Russia

E-mail: vsh@of.ugntu.ru

Abstract. The analysis of the relation between the wettability of mineral substance, the porosity and permeability properties of the rock and the nature of the distribution of hydrocarbons was made based on the core samples of the BS-1 and BS-2 productive strata of the Surgut oil and gas field. It was proposed to study the association of hydrophobic, hydrophilic, and mixed groups of collectors to different facies.

1. Introduction
The wettability of the rock forming the reservoir is an important parameter that determines the nature and efficiency of the development of any oil and gas field. The wettability of the surface of rocks affects the dynamics of filtration of fluids in the pore medium, as well as their distribution in the reservoir. The process of oil displacement by water largely depends on the wettability.

In practice, the underestimation of this factor can lead to a huge water cut of the extracted products, high value of residual oil in the reservoir, and, as a consequence, low production of oil reserves. Nowadays the study of the structure of the pore space and the assessment of wettability is an important task, the correct solution of which provides more efficient development of oil fields [1–13].

The purpose of this research is to study the wettability of mineral substance of the rocks of the BS-1-10 and BS-2-10 productive strata according to the laboratory analysis of the sample, as well as to study the relation between wettability and porosity and permeability properties and geological features of the strata.

The objects of study are located in the northern part of the Surgut oil and gas field, situated between the Kholmogorskii shore and the Komsomolskii dome-shaped plateau. The sediments of BS-1-10 and BS-2-10 beds are represented by the alternation of sandstone, aleurolite and argillite interlayers associated with the Neocomian sediments of the deltas and the shallow-water shelf [16].
It is necessary to note that a group of BS reservoirs in most fields is characterized by insufficiently high reserve production, with fast water cut (on average, the water content in the field exceeds production by about 10–15%) and water breakthroughs, which is caused by an insufficiently effective system of influence on the reservoir, due to the fact that injected water displace oil from the reservoir [16]. This problem may be directly related to the wettability of the pores of the reservoirs.

2. Materials and methods
In this research the level of wettability of the pore space surface of core samples was determined by the method of capillary intake during the simulation of residual water according to the Tulbovich method [14–15]. The method for the determination of wettability indicators involves the following stages:

1) Extraction of oil-saturated samples from oil, washing from salts and drying to constant weight;
2) Saturation of samples with a reservoir water model in order to determine porosity and pore volume;
3) Creation of residual water saturation in the samples using the method of centrifugation;
4) Saturation of the released pore volume with purified kerosene;
5) Spontaneous capillary intake of water-based oil-saturated samples;
6) Centrifuging the samples in water for additional kerosene displacement.

After each operation, the samples are weighed in order to determine the amount of kerosene displaced during the spontaneous absorption of water and subsequent centrifugation.

The parameter of wettability $M$ was counted according to the following formula:

$$M = \frac{P_2 - P_1}{P_3 - P_1},$$

where $P_1$ – the mass of the initial water-kerosene-saturated sample; $P_2$ – the mass of the sample after the spontaneous absorption of water and the kerosene displacement after 20 hours of sample exposure in water; $P_3$ – the sample mass after centrifuging process.

Parameter value $0 \leq M < 0.2$ characterizes the surface of the rock as purely hydrophobic, with $0.8 < M \leq 1$ – rock surface is purely hydrophilic. With parameter value $0.6 < M < 0.8$ – the surface of the rock is characterized as predominantly hydrophilic, with $0.2 < M < 0.4$ – as predominantly hydrophobic, and with $0.4 < M < 0.6$ – the surface of the rock has a mixed level of wettability [8].

The analysis of the data shows that the wettability of the investigated samples varies within significantly wide limits, from purely hydrophilic to purely hydrophobic. A characteristic feature of the studied samples is a very small number among of samples with an intermediate level of wettability. In other words, the studied sample is characterized by a clearly expressed polarity of wettability. The surface condition of the pore space is either hydrophilic or hydrophobic.

3. Results and discussion
The table shows the correlation coefficients for the entire sample of the main porosity and permeability properties of core samples.

As it can be seen, the wettability parameter $M$ has a good negative correlation with porosity $m$, permeability $K$ and displacement coefficient $K_d$, as well as satisfactory positive correlation with residual water saturation coefficient $K_{w}$. However, during the analysis of the distribution of these parameters in relation to each other, it can be seen that the correlation coefficients obtained over the entire sample volume describe the distribution data not precisely, except for the $m$-$K_{w}$, $m$-$K_d$ and $K$-$K_d$ ratios, which characterize the entire volume of the investigated sample.

Table 1. Correlation diagram for the main porosity and permeability properties of core samples
Depending on the prevailing type of wettability of the studied core samples, the groups were distributed as follows: four wells were assigned to the hydrophilic group, two wells - to the group with intermediate type of wettability, one well - to the hydrophobic group.

According to the nature of the distribution of points in the figure, the following conclusions can be made: the wettability parameter is practically independent of the displacement coefficient for the hydrophilic and intermediate groups; for a hydrophobic group, this dependence is slightly pronounced and inversely proportional. The value of the average coefficient value of displacement increases from the hydrophilic to the hydrophobic group and is 56.8; 67 and 73.3% respectively. The value of the dispersion of hydrophobic group is much smaller than that of the intermediate and hydrophilic groups, the dispersion values of which are almost equal.

On the basis of the data of [5, 7], it was found that the rocks forming the reservoir are hydrophilic before the migration of oil and gas into the trap. The hydrophobicity of the reservoir occurs during the physicochemical interaction of migrating hydrocarbons with the reservoir rock. Different wetting patterns result from the fact that the inner surface of the pores consists of various minerals with different chemical and adsorption properties, as a result of which the components of the oil are selectively adsorbed on the surface. Moreover according to the research works [4, 6], the wettability of the rock depends on the structure of the pore space, the physicochemical properties of saturating liquids and the content of trapped (relic) water in it.

| parameters                               | Porosity (m, %) | Permeability (K, mD) | Residual water saturation coefficient (K_{res}, %) | Displacement coefficient (d, %) | Wettability parameter (M) |
|------------------------------------------|-----------------|----------------------|-----------------------------------------------|--------------------------------|--------------------------|
| Porosity (m, %)                          | 1               |                      |                                               |                                |                          |
| Permeability (K, mD)                     | 0.6497          |                      |                                               |                                |                          |
| Residual water saturation coefficient    | -0.5501         | -0.4704              |                                               | 1                              |                          |
| (K_{res}, %)                             |                 |                      |                                               |                                |                          |
| Displacement coefficient (d, %)          | 0.5849          | 0.6055               | -0.2179                                       | 1                              |                          |
| Wettability parameter (M)                | -0.6794         | -0.7949              | 0.5126                                        | -0.7235                        | 1                        |
Figure 1. Dependence of distribution of wettability parameter $M$ from the displacement coefficient $K_d$

Since, according to the research work [9, 16], the accumulation of BS-1 and BS-2 strata was performed under the conditions of deltas and the shallow shelf, the core samples can be assigned to different types of facies environments by wettability and clay content:

- The samples of the hydrophobic group according to the sorting degree of the composing particles can be assigned to the deposits of the delta channels, in particular the group of samples of wells 1973 and 364 (samples 5 and 6) with high reservoir properties, reasoned by the formation of a well-sorted medium and grained sandy material amount of clay material and, accordingly, high reservoir properties, as evidenced by high average values of porosity, permeability, displacement coefficient and low coefficient of residual water saturation, low dispersion values of these parameters (except permeability) and the average content of particle size greater than 100 mcm 75.1% (mass);

- Groups with intermediate and hydrophilic wettability types can be attributed to channel facies deposits with low gradients of slope or inter-channel zones made by fine- and medium-grained sandstones poorly sorted with a large amount of clay material, and, as a result, less reservoir properties, as evidenced by lower average values of porosity, permeability and displacement coefficient for these groups relative to the group with hydrophobic type of wettability, higher values of the spread of points (except permeability), and high content of particles smaller than 100 mcm -41.6% (mass) for a group with an intermediate of 42.7% (mass) for hydrophilic type of wettability.
4. Conclusions
According to the results of the study of core samples of BS-1-10 and BS-2-10 strata, it can be concluded that when these strata are filled with oil in sediments with high porosity and permeability, formed of well-sorted medium and coarse sandstones (channel facies), due to the weakness of the capillary forces, a breakthrough of water film occurred on the grains of the mineral substance of the rock, which led to their hydrophobization. This fact is confirmed by the increase in the hydrophobicity of the samples of this group with increasing porosity and permeability.

In the group of samples with an intermediate type of wettability (aleurolite-siltstone sediments of interchannel facies), taking into account the smaller pore size and, as a consequence, a higher action of capillary forces, the samples are hydrophobic, apparently due to the presence of clay material capable of adsorbing a large amount of asphaltenes.

References
[1] Gudok N S, Bogdanovich N N and Martynov V G 2007 Determination of the physical properties of oil and water-containing rocks (Moscow: Nedra-Business Center LLC)
[2] Gurbatova I P, Melekhin S V, Chizhov D B and Fairuzova Y V 2016 Some specific features of studying wetting ability of complex carbonate reservoirs by laboratory methods Geology, geophysics and development of oil and gas fields 1 43–7
[3] Zlobin A A and Yushkov I R 2014 About the Mechanism of Hydrophobization of Surface of Rock in Oil and Gas Reservoirs Bull. of Perm Univer. Geology 24(3) 68–79
[4] Mikhailov N N 1992 Residual oil saturation of reservoirs under development (Moscow: Nedra)
[5] Mikhailov N N, Motorova K A and Sechina L S 2016 Geological factors of wettability of reservoir rocks of oil and gas Business magazine Neftegaz RU 3 80–90
[6] Mikhailov N N, Sechina L S and Motorova K A 2012 Role of clay minerals in formation of the adsorption-connected oil in rock-collectors of hydrocarbonic raw materials Georesources, geoenergetics, geopolitics 5 51–62
[7] Mikhailov N N, Gurbatova I P, Motorova K A and Sechina L S 2016 New representations of wettability of oil and gas reservoirs Oil Industry 7 80–5
[8] Mikhailov N N, Sechina L S and Gurbatova I P 2011 Wettability indicators in the porous environment and dependence between them Georesources, geoenergetics, geopolitics 1(3) 10–20
[9] Mikhailov N N, Semenova N A and Sechina L S 2010 The conditions of microstructure wetting forming and their influence on filtration-measurement characteristics of productive strata Georesources, geoenergetics, geopolitics 1(1) 30–8
[10] Nesterenko N Yu 1995 Wettability of reservoir rocks by reservoir fluids Geology of oil and gas 5 10–5
[11] Akhmetov R T and Mukhametshin V V 2018 Estimation of displacement coefficient with due account for hydrophobization of reservoir using geophysical data of wells IOP Conf. ser. Earth Env. 194(6) 062001
[12] Mukhametshin V Sh, Kotenev Yu A and Sultanoval Sh Kh 2018 Assessment of the Need to Stimulate the Development of Hard-to-Recover Reserves in Carbonate Reservoirs IOP Conf. ser. Earth Env. 194(8) 082027
[13] Akhmetov R T, Mukhametshin V V and Andreev A V 2017 A quantitative assessment method of the productive formation wettability indicator according to the data of geophysical surveys SPE Russian Petroleum Technology Conf. 16–18 Oct 2017 (Moscow: Society of Petroleum Engineers) p 12
[14] Tulbovich B I 1975 Collector properties and surface chemistry of productive rocks (Perm. Perm book publishing house).
[15] Tulbovich B I 1979 Methods of studying reservoir rocks of oil and gas (Moscow: Nedra)
[16] Bagautdinov A K et al 1996 Geology and development of the largest and unique oil and gas fields in Russia vol 2 (Moscow: VNIIOENG)