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POSSIBILITIES FOR DETECTING RESERVOIR WETTABILITY AND BITUMINISATION BASED ON INTEGRATED PETROPHYSICAL CORE AND WELL-LOGGING DATA

Galkin S.V.[1], Kolychev I.J.[2], Savitsky Y.V.[3*], Shumilov A.V[4], Gurbanov V.Sh.[5,6], Abbasova G.G.[7]

[1-4]Perm National Research Polytechnic University, Russia
[5]Ministry of Science and Education of the Republic of Azerbaijan, Institute of Oil and Gas, Azerbaijan
9, Baku, F.Amirov str., Baku, AZ1000
[6]Baku State University, Azerbaijan
33 Acad. Zahid Khalilov str., Baku, AZ1148
[7]Azerbaijan State Oil and Industry University, Azerbaijan
20, Azadlig ave., Baku, AZ1010
Corresponding author: yansavitsky@yandex.ru

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Summary. For some complex Visean oil-saturated intervals of the fields of the Perm Krai, a high electrical resistance has been established. This can be explained by the hydrophobicity and bitumen content of the reservoirs. The assessment of these parameters was carried out analysing a petrophysical and geophysical data for a number of large oilfields. X-ray tomography was used to assess the wettability of the core samples, which was compared with lateral log data. Comparison of core X-ray tomography results with electrical logging data shows that at resistivity over 200 ohm·m the rocks are hydrophobic, and at a resistivity over 600 ohm·m they practically do not take water. The bituminisation of the reservoirs was analysed from the core material, taking into account the porosity according to the nuclear logging data, as well as the electrical resistivity from the lateral and micro-lateral logs. We demonstrate that log porosity and resistivity data can be used in developing algorithms, in building wettability and bituminisation maps of the main fields. These maps can be further utilized in building 3D reservoir models and in optimization of the secondary recovery operations in the field. The analysis of all the data suggests that open porosity is the key parameter controlling bituminisation. According to the obtained results, algorithms have been developed to predict the formation bituminisation using a set of logging methods. The results of the developed method were applied in digital geological and technological modelling of deposits with different types of wettability and bitumen content.

1. Introduction

Pore characteristics are fundamental to understanding the subsurface heterogeneity and constituent fluid flow in reservoir rocks (Johnson et al., 2006).

The north of the Perm region in Russia is a promising area for oil production development, where several new oil fields have recently been discovered. In this area, recoverable reserves of a single field often exceed 40 million barrels of oil. Most of the production facilities are characterized by a low degree of reserves recovery. High economic prospects of this region are also associated with low oil viscosity (1-3 mPa • s) and relatively high reservoir permeability (100 • 10-3 μm^2). The Visean complex is one of the largest in terms of oil reserves and it is represented by fine-grained and medium-fine-grained sandstones with porosity of 8-20%.

High porosity intervals are typically light grey sandstones, while low porosity intervals can be bituminous and dark in colour. For a significant number of oil-saturated intervals, a high electrical resistivity of rocks of more than 200 Ohm·m, and in some cases more than 1000 Ohm·m, has been established. According to theoretical concepts, abnormally high resistivity can be explained by rocks hydrophobicity. This topic was covered in reports Salah Al-Ofi et al. (2017 and 2018), as well as in paper (D'jakonova et al., 2021).

Data of reservoirs wettability is extremely important for efficient planning of oil production and especially for water flooding. The possibility of using wettability change as the main recovery mechanism in the process of enhanced oil recovery has only become an important topic in the research region in recent years. This is despite the fact that it was first recognized in 1959 by Wagner, Leach and tested in the field in 1962 (Wagner and Leach, 1959; Leach and Wagner, 1962).

Efimov et al. (2016) show that problems with reservoir injection optimization in the Visean objects of Perm region are often related to the rocks of increased resistivity. In case of low porosity reservoirs, the increased resistivity is typically associated with their bituminous content (Mukhametshin and Galeev, 2014), which reduces well productivity.

2. Materials and methods

The tomographic method has been applied to 47 core samples, 30 mm in size from the Perm region. All core samples were preliminarily extracted, open porosity (ϕ), irreducible water saturation (Swi), specific electrical resistivity of water-saturated sample (Rws) and the sample with residual water (Rrw) were determined. Open porosity was determined by the liquid saturation and hydrostatic weighing method; irreducible water saturation was determined by the capillarimetric method with air displacement pressure of up to 0.3 MPa through semipermeable membranes with a breakthrough pressure of 1.5 MPa. Oil-saturated core samples are characterised by a wide range of reservoir properties: ϕ of 10.1-22.3% (16.2% on average), Swi of 3.3-24.2% (9.0% on average).

The experimental tomograms of the cores in their dry state and saturated with sodium iodide aqueous solution with NaI concentration of 300 g/l were acquired. Saturation was achieved by gradually filling an evacuated sample chamber with preliminary evacuated NaI solution. This step was followed keeping the samples in the solution. White colour on the tomograms corresponds to calcification sites characterised by relatively high density; their configuration can be used to compare the tomograms of dry and saturated samples.

Tomography of dry and saturated samples was performed using the same parameters of the position and rotation of the stage, as well as the distance to the X-ray gun and the detector. The shooting parameters were as follows: voltage of 155-175 kV, current of 60-80 μA, copper filter was 0.5 mm thick. After 3D reconstruction of the tomography results, the sample volumetric models were compared. For comparison, both reconstructions were reduced to the same brightness according to the histogram; the upper and lower 2.5 mm ends of each sample were avoided to eliminate artifacts arising during X-ray shooting (Gurbanov et al., 2019).

For the pore volume calculation, image binarisation was carried out with the purpose to discriminate the pore space. Subsequently, the cutoff corresponding to the "rock-air" interface was drawn on the histogram to highlight the pore volume. Tomographic porosity of dry and saturated samples was calculated as the ratio of the pore volume to the entire sample volume. The use of the NaI additive to the aqueous solution does not change its filtration characteristics. The density of the solution with NaI differs sharply from the density of the void space in the dry state. Thus, the sample wettability can be assessed comparing the dry and NaI solution-saturated tomograms. The dry pores on the tomograms are displayed as black, while the saturated ones will change colour to light grey. This makes it possible to determine the fraction of the pore volume saturated with fluid (Berg et al., 2014). The coefficient of impregnation CI was calculated as the ratio of the difference in the pore volume between the dry (V1) and the saturated sample (V2) to the pore volume in the dry sample (V1):

$$\mathrm{CI} = \frac{V_1 - V_2}{V_1} * 100\%. \quad (1)$$

The impregnation coefficient is used as an indicator of the reservoir wettability. We have established a conditional division into three classes. Notably, at CI values over 90% the sample was classified as hydrophilic, at 90-50% – as having signs of hydrophobicity, at 50-10% – as mainly hydrophobic, and, finally, if the impregnation was below 10% – as hydrophobic.

Pore-type reservoirs are distinguished by complex interpretation of gamma-ray, neutron-neutron, sonic, and caliper logs. The formation saturation is determined from electrical resistivity using induction (IK), laterolog (BK), and microlaterolog (MBK).

To create an algorithm for forecasting bituminisation, data from 376 wells with lateral logging data, 155 wells with micro-lateral logging data, and 27 wells with coring were analyzed. In addition to BK and MBK data, all intervals of the well section are characterized by the values of porosity and residual water saturation according to logging interpretation data, as well as in the case of sampling with a core description, indicating the presence of bituminisation. All wells belong to the fields of the Solikamsk depression (Gurbanov, Narimanov, 2019).

The water saturation is most reliably evaluated in the far field by the laterolog, including formation resistivity greater than 100 ohm·m. Due to the usage of the shielding electrodes, the drilling fluid effect is minimised and the vertical resolution can be as low as 50 cm (20 inches), allowing thin bed evaluation. The most reliable formation resistivity from BK (RBK) is obtained in wells filled with water-based mud having resistivity of 0.03-3 ohm·m and for the intervals with bed thickness greater than 0.8 m (30 inches).

A subset of 47 core samples was analysed to compare wettability from X-ray tomography with the laboratory measurements of resistivity. The resistivity of the core samples was measured using the two-electrode method at a frequency of 1000 Hz with complete (100%) and residual saturation of cylindrical samples with formation water marked by the X-ray contrast agent (Gurbanov et al., 2021).

Oil-saturated intervals of several fields are classified according to the signs of wettability changes (hydrophobisation) and bituminisation. The data on the results of the predictive assessment are entered into 3D digital geological models. The models were built for two fields of the Solikamsk depression – Unvinskoye and Sukharevskoye. As a result, the fraction of hydrophobised and bituminised sections in the overall oil-saturated thickness was calculated for the entire territory.

3. Results

3.1. Hydrophobisation evaluation from core X-ray tomography

Previous studies have applied a variety of conventional techniques to porous media to qualitatively and quantitatively characterise the pore size of complex geological materials. Centrifugation, isometric drying, Amott and adsorption methods are most frequently used for assessing wettability on cores (Dixit et al., 2000). Comparison of wettability determination by different methods shows different results (Gurbatova et al., 2016), due to indirect characterisation. According to these authors, the X-ray core tomography method is the most informative for wettability. Using this direct imaging method, studies have examined pore systems and the surrounding matrix visually (Bultreys et al., 2016; Milliken, Curtis, 2016).

This method allows visualizing the rock pore space including the assessment of the degree of aqueous solution penetration into the core samples (Efimov et al., 2015).

Examples of tomograms of sandstones with different types of wettability are shown in Fig. 1. The NaI solution fills almost the entire pore space of the hydrophilic sample, changing the general background colour of the rock skeleton to light grey (Fig. 1a). For the saturated sample with CI in the 50-90% range, we observe that some of the larger pores are displayed in black in the central part of the tomogram, i.e. those pores were not accessed by the NaI solution (Fig. 1b). The proportion of such pores increases for the samples with strong signs of hydrophobicity at CI of 10-50% (Fig. 1c). For hydrophobic sandstones the images of the dry and saturated pores volumes in the central part of the tomograms are practically the same, which indicates absence of NaI impregnation (Fig. 1d).

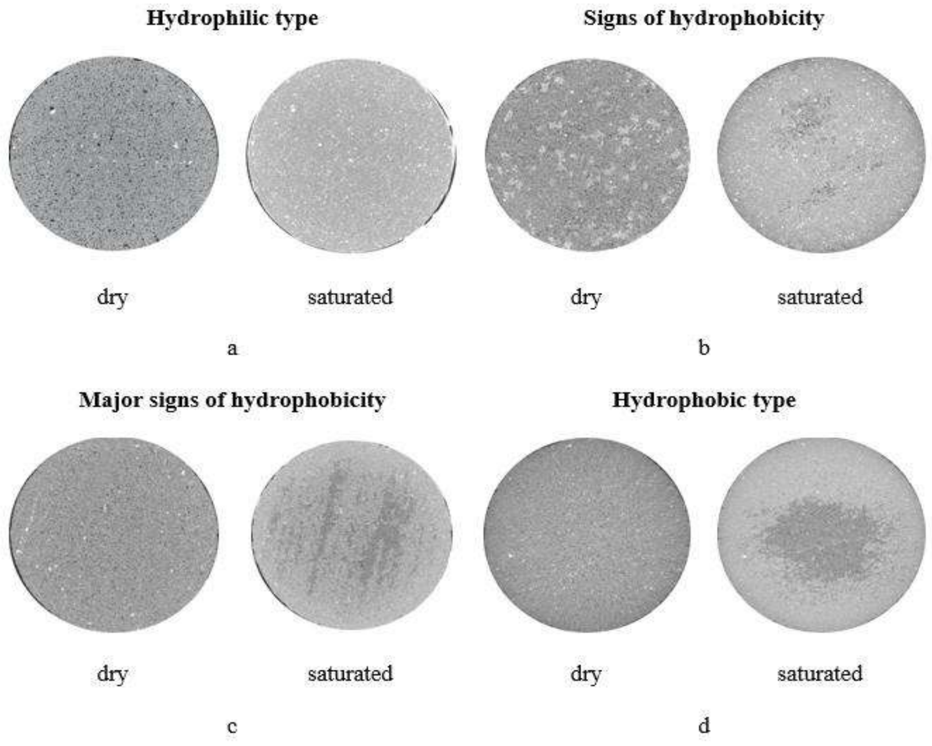

Fig. 1. X-ray tomograms of dry and NaI solution-impregnated sandstone cores with different wettability

Fig. 2a and 2b are log plots of the Visean interval from two wells in the Unvinskoye Field.

Increased values of resistivity from microlaterolog (R_{MBK}) are interpreted as intervals of bituminisation, represented in cores as dark-coloured (almost black) sandstones with reduced open porosity. These intervals are characterised by low value of GR log and are often included in recoverable oil reserves, although their real share in oil production is minimal.

Comparison of core X-ray tomography results with electrical logging data shows that the rocks are hydrophobic at resistivity over 200 ohm·m, and they practically do not take water at a resistivity over 600 ohm·m. At the same time "black sandstones" were encountered in less than 20% of the Perm region wells, that is why this problem has not been studied in detail so far. Fig. 2 shows the wells that penetrated dark grey to black bitumen-filled sandstones sampled by core.

In well A (Fig. 2a), the formations Bb1 and Bb2 are characterized by relatively low resistivity R_{BK} due to their hydrophilic nature. The only exception is the lowest interval with a thickness of 1 m (2048 m depth), for which resistivity exceeds 200 ohm·m in both BK and MBK. Thus, drilling mud does not enter this hydrophobic interval, and it can be interpreted as bituminous. Wettability assessment results from electrical logging is fully consistent with the core data analysis, including X-ray tomography. Except of the lowest interval with dark grey bituminised core, the rest are light grey sandstones of different grains. The Bb3 and Bb4 formations are interpreted as bitumen-saturated according to logs, as they have increased BK and MBK values. Moreover, the resistivity exceeds 1400 ohm·m for the Bb3 formation. Cores obtained from both formations are bituminised, and the entire Bb3 formation is represented by the classic “black sandstone” and Bb4 formation – by dark grey sandstone.

In well B (Fig.2b), the Bb2 formation reservoirs (2043 m depth) are characterised by relatively low BK and MBK readings and light grey core without signs of bituminisation. These intervals can be identified by the hydrophilic type of the oil-saturated sandstone. The upper part of the Bb3 formation (2049 m depth) is also made up of light core for which resistivity R_{BK} exceeds 200 ohm·m and R_{MBK} is greater than 100 ohm·m. Decreased MBK values show that drilling mud has entered the hydrophobic reservoir reducing the resistivity in the bottomhole zone. The bottoms of the Bb3 (2051 m depth) and the Bb4 formations are represented by dark bituminised core. These intervals have BK and MBK readings over 200 ohm·m. High MBK values in this case show that drilling fluid has not filtrated into the formation due to its bituminisation. Therefore, three possible cases of reservoirs with different wettability can be distinguished: (1) hydrophilic with reduced BK and MBK readings, (2) hydrophobic oil-saturated with high BK and low MBK readings, and (3) bituminous with high BK and MBK readings.

As a result of core analysis, it was found that all samples saturated with formation water have resistivity within the range of 0.6 to 4 ohm·m. The ratio of the studied samples to the permeable part of the section confirms the low values of the water-saturated samples. The low resistivity values in the water-saturated samples confirms their affinity to the permeable reservoir sections. The samples with residual water saturation show a dramatic core resistivity increase to 24 -1200 ohm·m.

Comparison of the core resistivity values with log resistivity shows positive correlation, as sandstone hydrophobisation universally reduces their conductivity. It should be noted that core preparation for laboratory experiments (extraction, heating etc.) affects resistivity measured, whereas shoulder effects, vertical resolution, and washouts can impact log resistivity data. Further complication results from the sample size discrepancies: inches in core samples versus meters in logs (Kerimov et al., 2020).

Interval resistivity from logs shows that in several cases abnormally high values were observed, in 53% of the cases they were exceeding 200 ohm·m and in 13% of the cases the reading were above 600 ohm·m. Core samples wettability results (CI) are compared with interval laterolog resistivity in Table 1.

For the intervals with R_{BK}< 30 ohm·m all X-ray tomography-studied core samples were assessed as hydrophilic (CI > 0.90). Cores with R_{BK} of up to 120 ohm·m were classified as mainly hydrophilic. At resistivity readings of 200-600 ohm·m most samples show some signs of hydrophobic behaviour with 0.5-0.9 CI range, whereas higher log resistivity mostly corresponds to samples with CI < 0.5, i.e., showing significant signs of hydrophobisity. Finally, two out of three samples with CI < 0.1 (hydrophobic) come from intervals with log resistivity above 1000 ohm·m.

Therefore, the following criteria for the wettability classification of the oil-saturated Visean reservoirs can be formulated:

– in the intervals with R_{BK} below 120 ohm·m, the reservoirs are hydrophilic;

– in the R_{BK} range from 120-200 ohm·m, the wettability assessment is unclear;

– starting from R_{BK} over 200 ohm·m, reservoirs hydrophobisation processes start to manifest, rendering mostly hydrophobic reservoirs;

– at R_{BK} over 600 ohm·m, the reservoirs are totally hydrophobic.

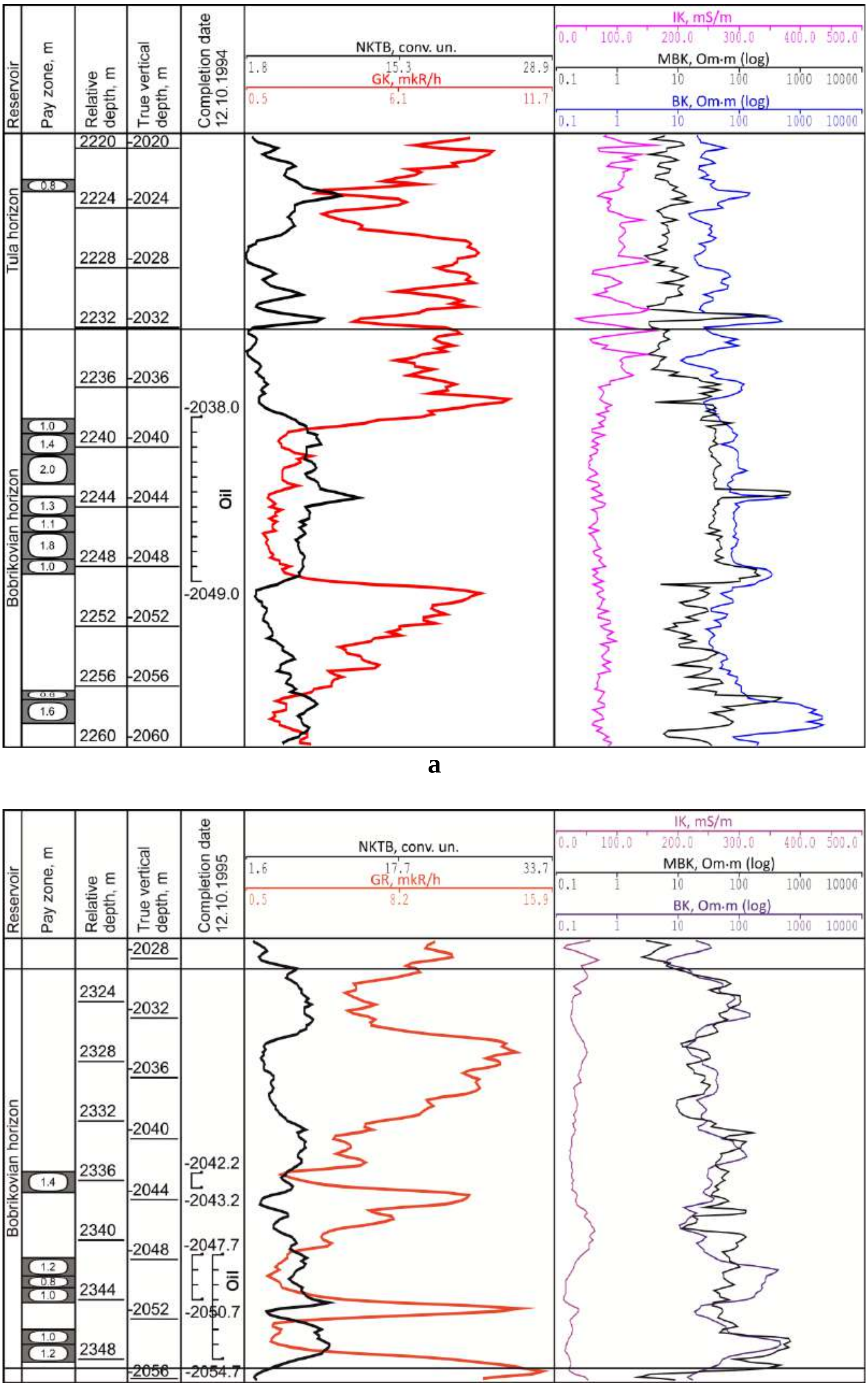

Fig. 2. Log displays of two wells (a) and (b) from the Unvinskoye Field. Horizontal scales: NKTB – dual spacing thermal decay-time logging, conventional unit; GK – gamma-ray logging, μR/hour; IK – induction well logging, mS/m; BK – laterolog, Om·m; MBK – microlaterolog, Om·m

Table 1

Core wettability evaluation from X-ray tomography compared with corresponding interval resistivity from laterolog (BK). Number of cores in each category is shown.

Electrical resistivity from BK (R_{BK}) ohm·m	Impregnation coefficient (CI), unit fraction			
	<0,10	0,10-0,50	0,50-0,90	>0,90
<30	0	0	0	4
30-80	0	0	3	7
80-120	0	1	0	4
120-200	0	0	2	1
200-300	1	1	2	1
300-400	0	1	5	1
400-600	0	1	4	2
600-1000	0	1	1	0
>1000	2	0	2	0
Total	***3***	***5***	***19***	***20***

3.2. Reservoirs bituminisation evaluation from petrophysical core and electrical logs

Table 2 shows data on core bituminisation occurrence as compared to core open porosity (ϕ). All five samples with ϕ <12% show bituminisation, whereas all 22 samples with ϕ > 16% show none. Within 12-16% porosity range, bituminisation probability gradually decreases.

Table 2

Bitumen occurrence in core data set of 47 samples versus core porosity

Core porosity	Without bitumen	With bitumen	Total	Percentage of samples whith bitumen
below 12%	0	5	5	100
12% to 14%	3	6	9	66.6
14% to 16%	8	3	11	37,5
16% to 18%	4	0	4	0
18% to 20%	9	0	9	0
over 20%	9	0	9	0
Total	***33***	***14***	***47***	***29.8***

Petrophysical indicators of sandstone bituminisation obtained on core can only be useful if they can be also applied in log interpretation. To determine the error in wireline log-based open porosity (ϕwl) and irreducible water saturation (Swiwl) we used our core data and compared with the corresponding log interval averages. A combination of GR and Neutron logs was used to quantify ϕwl. The ϕwl = f (ϕc) dependence can be described by the positive linear function. In general, the correlation between them is positive, albeit not strong (r = 0.55). Nonetheless, it does show that log data on ϕwl can be feasible in reservoir bituminisation delineation. On the contrary, the comparison of residual water saturation in core (Swic) and log data (Swiwl) shows no correlation between them (r = 0.14). Therefore, the Swiwl indicator is excluded from further analysis.

Analysis of 68 oil-saturated sandstone intervals shows bituminisation in 21% of cases (14 out of 68). The complex log interpretation was available for almost the entire data set with a few exceptions for microlaterolog (MBK). Based on the joint analysis of core and wireline log-based petrophysical we established that bituminous content is practically excluded at a porosity ϕwl>16% (30 out of 31 intervals). Reservoirs bituminisation is most probable at ϕwl<12% (3 out of 4 intervals). In the ϕwl range from 12-16% reservoir bituminisation probability naturally decreases (Table 3).

Table 3

Bitumen occurrence in cores as compared to log porosity

Log porosity	Without bitumen	With bitumen	Total	Percentage of samples with bitumen
below 12%	1	3	4	75.0
12% to 14%	4	6	10	60.0
14% to 16%	19	4	23	17.3
16% to 18%	11	1	12	8.3
18% to 20%	12	0	12	0
over 20%	7	0	7	0
Total	***54***	***14***	***68***	***20.6***

Reservoirs bituminisation is not typical for hydrophilic reservoirs with R_{BK} below 60 ohm·m (13 out of 14 intervals) (Table 4).

Table 4

Bitumen occurrence in core and corresponding BK resistivity values

BK log ranges	Without bitumen	With bitumen	Total	Percentage of samples whith bitumen
below 60 ohm·m	13	1	14	7.1
60—120 ohm·m	13	3	16	18.7
120—200 ohm·m	6	4	10	40.0
200—600 ohm·m	15	5	20	25.0
over 600 ohm·m	5	1	6	16.7
Total	***52***	***14***	***66***	***21.2***

Analysis of the data presented in Table 5 suggests that low MBK values are characteristic of good mud filtrate penetration into the formation, which is a consequence of no reservoir bituminisation (at MBK < 10 ohm·m 18 out of 18 core show none). As the MBK values grow, bituminisation probability gradually increases, and at MBK > 200 ohm·m bituminised core was found in 3 of 3 cases.

Table 5

Bitumen occurrence in core and corresponding MBK resistivity values

MBK log ranges	Without bitumen	With bitumen	Total	Percentage of samples whith bitumen
below10 ohm·m	18	0	18	0
10–30 ohm·m	13	3	16	18.7
30–100 ohm·m	6	3	9	33.3
100–200 ohm·m	2	3	5	40.0
Over 200 ohm·m	0	3	3	100
Total	***39***	***12***	***51***	***23.5***

The analysis of all the data suggests that open porosity is the key parameter controlling bituminisation. In absence of interval porosity data the bituminisation forecast may be unreliable. With consideration of the results obtained algorithms have been developed for reservoir bituminisation forecasting using a complex of radioactive and electrical logging methods. The bituminous content forecast algorithm of the intervals with oil-saturated reservoirs can be formulated as follows:

– $\phi wl < 12\%$ – pervasive bituminisation, $\phi wl \geq 16\%$ – no bituminisation,

– $R_{BK} < 60$ ohm·m – no bituminisation,

– $R_{MBK} < 15$ ohm·m – no bituminisation, $R_{MBK} \geq 200$ ohm·m – pervasive bituminisation,

– when $R_{BK} \geq 60$ ohm·m, $15 \leq R_{MBK} < 200$ ohm·m, and at $\phi wl = 12\text{-}14\%$, the intervals are assessed as bituminous, but for $\phi wl = 14\text{-}16\%$, it is concluded that there is no bituminisation.

The forecast error when using this classification in field studies with the complete log data set is estimated as 4% (2 out of 50 intervals analysed). The error slightly increases when no MBK data is available (7 out of 65 intervals). In the absence of resistivity logs, the forecast error increases to 15% (7 out of 65 intervals). This clearly indicates that the most reliable prediction of reservoir bituminisation can be achieved when full set of wireline data is available.

3.3. Lateral distribution of wettability and bituminisation of oil-saturated sandstone reservoirs

Based on the formulated criteria and the results of 3D modelling, the calculation of hydrophobised and bituminised sections for the entire study area was carried out. Figs 3 and 4 show maps of the reservoir hydrophobisation and bituminisation built for two oil fields. Complete absence of hydrophobisation (bituminisation) in the maps is depicted with light grey colour, whereas dark color corresponds to the maximum hydrophobisation (bituminisation).

The Unvinskoye Field section is mainly characterized by high resistivity, allowing pervasive hydrophobisation being predicted (Fig. 3a). However, the western and central parts of the field are mainly characterised by high porosity reservoir sandstones, so that the bituminisation is limited. Intense bituminisation is forecasted in the eastern flank of the field (Fig. 3b), where reservoirs with low porosity are localized. Core data from the Unvinskoye Field confirm that oil-saturated reservoir bituminisation is typical for it. In 9 cases out of 18 analysed intervals bitumen was found in the core (Gurbanov et al., 2022).

The wettability zonation in the Sukharevskoye Field section shows the hydrophobised reservoir areas localize in the crestal part of the structure, whereas the hydrophilic section is predicted in the northern part of the structure (Fig. 4a).

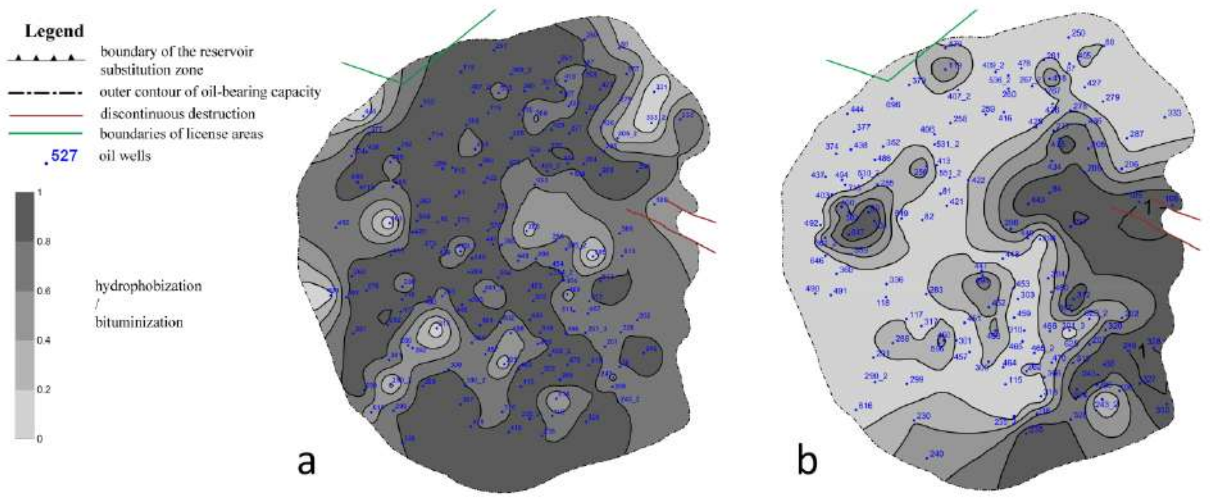

Fig. 3. Reservoir hydrophobisation (a) and bituminisation (b) maps of the Bb Formation, Unvinskoye Field

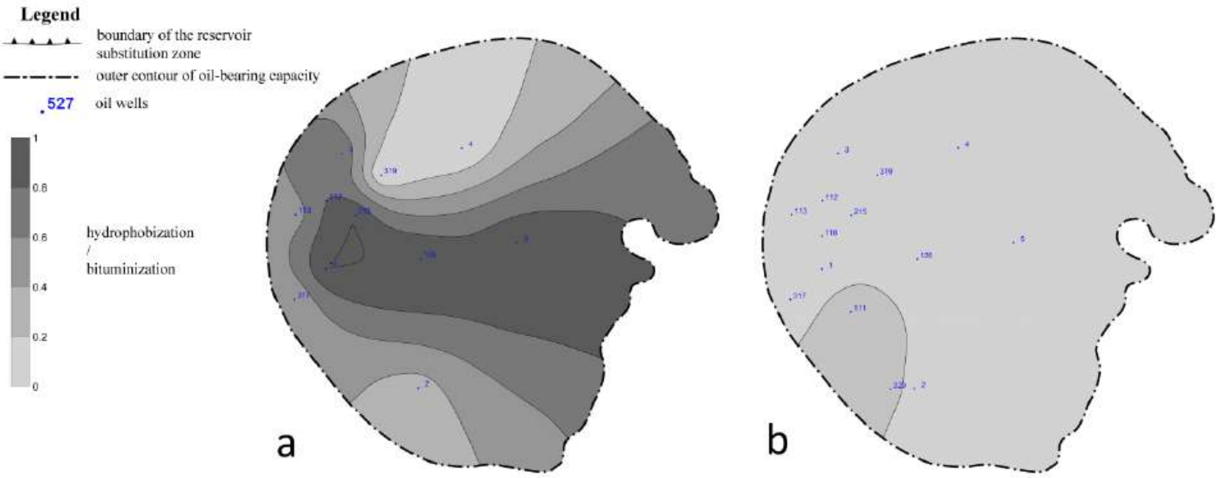

Fig. 4. Reservoir hydrophobisation (a) and bituminisation (b) maps of the Bb Formation, Sukharevskoye Field

Nonetheless, the bituminisation prediction of the crestal zone is unlikely, as it is characterised by high reservoir porosity. Core data from the Sukharevskoye Field reveal no bituminisation, as any signs of bituminisation were detected in any of the 28 sampled intervals.

4. Discussion

The results of identifying zones of hydrophobic and bituminous reservoirs can be used when planning measures to increase oil production. Under such conditions, the implementation of standard water flooding of reservoirs may be ineffective due to hydrophobisation of the rocks. According to the experience, proppant hydraulic fracturing can be proposed for the study area in areas of highly porous reservoirs with high potential production rates (Votinov et al., 2018; Zhang et al., 2019; Galkin et al., 2022)., Hydraulic fracturing can be economically ineffective for bituminous rocks, due to high costs; in such conditions, radial drilling technology can be recommended (Kochnev et al., 2018; Reinsch et al., 2018; Galkin et al., 2019).

Abnormally high resistivity of oil-saturated reservoirs of the Perm region is considered to be related to their wettability alteration (hydrophobisation) and bituminisation. To predict these processes, both core and log data must be jointly analysed. High porosity measured in cores and log data interpretation is indicative of hydrophilic sandstone reservoir, whereas low porosity and relatively high resistivity are the most reliable indicators of wettability changes resulting in bituminisation. We demonstrate that log porosity and resistivity data can be successfully used in developing algorithms, when applied to field data, can be instrumental in building wettability and bituminisation maps of the main fields. These maps can be further utilized in building 3D reservoir models and in optimization of the secondary recovery operations in the field.

5. Conclusions

As a result of the studies, it was found that according to the data of combining the methods of lateral and microlateral electric logging, the areas of development of bituminisation and hydrophobisation of reservoirs can be identified. The operation of injection wells in such areas is often characterised by reduced injectivity, which makes standard flooding ineffective. One of the ways to optimise injection is to create relatively long highly conductive channels that allow increasing the degree of reservoir sweep by the displacement process, which can be solved by using radial drilling technology. Under the conditions of development of hydrophobic sandstones, the alkaline flooding technology can also be considered promising, which can lead to an increase in oil mobility due to the removal of rock of poorly soluble substances. Thus, for reservoir hydrophobisation development zones established according to the developed method, a number of promising reservoir stimulation technologies can be recommended.

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ВОЗМОЖНОСТИ ОБНАРУЖЕНИЯ СМАЧИВАЕМОСТИ И БИТУМИЗАЦИИ КОЛЛЕКТОРОВ ПО КОМПЛЕКСНЫМ ПЕТРОФИЗИЧЕСКИМ ДАННЫМ КЕРНА/КАРОТАЖА

Галкин С.В.[1], Колычев И.Ю.[2], Савицкий Ю.В.[3*], Шумилов А.В.[4], Гурбанов В.Ш.[5,6], Г.Г. Аббасова[7]
[1-4]Пермский национальный исследовательский политехнический университет, Россия
614990, Пермь, Комсомольский просп., 29
[5]Министерство науки и образования Республики Азербайджан, Институт нефти и газа, Азербайджан
AZ1000, Баку, ул. Ф. Амирова, 9
[6]Бакинский государственный университет, Азербайджан
AZ1148, Баку, ул. акад. Захида Халилова, 33
[7]Азербайджанский государственный университет нефти и промышленности, Азербайджан
AZ1010, Баку, просп. Азадлыг, 20
**Автор, отвечающий за переписку: yansavitsky@yandex.ru*

Резюме. Для некоторых нефтенасыщенных интервалов визейских отложений Пермского края по каротажу установлено аномально высокое электрическое сопротивление, что можно объяснить гидрофобизацией и битумизацией коллекторов. Оценка данных параметров проведена путем сопоставления петрофизических и геофизических исследований по ряду эксплуатационных объектов. Для оценки смачиваемости применена рентгеновская томография керна, результаты которой сравнивались с данными бокового электрического каротажа. Сравнение результатов рентгеновской томографии керна с данными электрического каротажа показывает, что при удельном сопротивлении более 200 Ом·м породы являются гидрофобными, а при значениях более 600 Ом·м практически не впитывают воду. Битумизация коллекторов оценивалась по данным исследований керна, что сопоставлялось с результатами определения пористости по гамма-каротажу, а также с удельным электрическим сопротивлением по боковому и микробоковому каротажу. Мы демонстрируем, что данные о пористости и удельном сопротивлении могут быть использованы при разработке алгоритмов, построении карт смачиваемости и битумизации основных месторождений. Эти карты могут быть далее использованы при построении трехмерных моделей пластов и оптимизации операций вторичного извлечения на месторождении. Анализ всех данных показывает, что открытая пористость является ключевым параметром, контролирующим битумизацию. С учетом проведенного анализа разработаны алгоритмы прогнозирования битумизации коллекторов на основе комплекса геофизических исследований скважин. Результаты разработанного метода применены при цифровом геолого-технологическом моделировании нефтяных месторождений с различными типами смачиваемости и битумизации. Также результаты выявления зон гидрофобных и битуминозных коллекторов могут быть использованы при планировании мероприятий по повышению нефтеотдачи.

Ключевые слова: *гидрофобизация, смачиваемость, битумизация, пористость, удельное электрическое сопротивление горных пород, рентгеновская томография керна, боковой электрический каротаж, микробоковой каротаж*

KERN/KAROTAJIN KOMPLEKS PETROFİZİKİ MƏLUMATLARINA GÖRƏ KOLLEKTORLARIN BİTUMLAŞMASININ VƏ İSLANMASININ MÜƏYYƏN EDİLMƏSİ İMKANLARI

Qalkin S.V.[1], Kolychev I.Y.[2], Savitsky Y.V.[3*], Şumilov A.V.[4], Qurbanov V.Ş.[5,6], Abbasova Q.Q.[7]
[1-4]Perm Milli Tədqiqat Politexnik Universiteti, Rusiya
614990, Perm, Komsomolski prosp., 29
[5]Azərbaycan Respublikasının Elm və Təhsil Nazirliyi, Neft və Qaz İnstitutu, Azərbaycan
AZ1000, Bakı, F.Əmirov küç., 9
[6]Bakı Dövlət Universiteti, Azərbaycan
AZ1148, Bakı, akad. Zahid Xəlilov küç., 33
[7]Azərbaycan Dövlət Neft və Sənaye Universiteti, Azərbaycan
AZ1010, Bakı, Azadlıq prosp., 20
**Yazışmalara məsul:yansavitsky@yandex.ru*

Xülasə. Quyuların karotaj məlumatlarından istifadə etməklə Perm diyarının Visean yataqlarının bəzi neftlə doymuş intervallarında anomal yüksək elektrik müqaviməti aşkar edilmişdir. Bu, anbarların hidrofobizasiyası və bitumlaşması ilə izah edilə bilər. Bu parametrlər bir sıra hasilat hədəfləri üçün petrofiziki və geofiziki tədqiqatların müqayisəsi yolu ilə qiymətləndirilmişdir. Nəmlənmə qabiliyyətini qiymətləndirmək üçün əsas rentgen tomoqrafiyası istifadə edildi, nəticələri yanal elektrik qeydləri ilə müqayisə edildi. Əsas rentgen tomoqrafiyasının nəticələrinin elektrik qeydiyyatı məlumatları ilə müqayisəsi göstərir ki, müqaviməti 200 Ohm·m-dən çox olan süxurlar hidrofobikdir, 600 Ohm·m-dən çox olduqda isə onlar demək olar ki, heç bir su qəbul etmirlər. Rezervuarın bitumlaşdırılması əsas məlumatlardan istifadə edilməklə qiymətləndirilmişdir, bu məlumatlar qamma şüaları ilə qeydiyyatdan istifadə etməklə məsaməliliyin təyini ilə, eləcə də yanal və mikroquyuların girişindən istifadə etməklə müəyyən edilmiş elektrik müqaviməti ilə müqayisə edilmişdir. Biz nümayiş etdiririk ki, məsaməlilik və müqavimət məlumatlarından əsas sahələr üçün alqoritmlər hazırlamaq və nəmlənmə qabiliyyəti və bitum xəritələrini qurmaq üçün istifadə etmək olar. Bu xəritələr daha sonra 3D rezervuar modellərinin qurulması və yataqda ikinci bərpa əməliyyatlarının optimallaşdırılması üçün istifadə oluna bilər. Bütün məlumatların təhlili göstərir ki, açıq məsaməlilik bitum əmələ gəlməsinə nəzarət edən əsas parametrdir. Bu təhlil əsasında quyuların karotaj məlumatlarının hərtərəfli toplusu əsasında lay bitumunun əmələ gəlməsinin proqnozlaşdırılması üçün alqoritmlər hazırlanmışdır. İşlənib hazırlanmış metodun nəticələri müxtəlif nəmlilik və bitum əmələgəlmə növlərinə malik neft yataqlarının rəqəmsal geoloji və texnoloji modelləşdirilməsinə tətbiq edilmişdir. Bundan əlavə, hidrofobik və bitumlu lay zonalarının müəyyən edilməsi gücləndirilmiş neftçıxarma tədbirlərinin planlaşdırılmasında istifadə edilə bilər.

Açar sözlər: *hidrofobizasiya, nəmlənmə qabiliyyəti, bitumlaşma, məsaməlilik, süxurların elektrik müqaviməti, rentgen nüvəli tomoqrafiya, Lateroloq, mikrolateroloq*