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Application of a Modular Dynamic Formation Tester on a Wire Line to Refine the Filtration Characteristics of the Production Formations of the Magovsky Oil and Gas Condensate Field

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Применение модульного динамического испытателя пластов на каротажном кабеле для уточнения фильтрационных характеристик продуктивных пластов Маговского нефтегазоконденсатного месторождения

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An important task in monitoring the development of hydrocarbon fields is to obtain data on the filtration characteristics of reservoirs and the properties of fluids in reservoir conditions. When using standard logging in the complicated conditions of low-permeability formations, poorly consolidated rocks and eroded wellbores, it is very difficult to perform reservoir pressure measurements, sampling with a detailed analysis of fluid properties. A study was carried out in order to clarify the filtration properties of the rocks of the geological section by the method of hydrodynamic logging with testing of the formations by a tester on a MDT logging cable (modular dynamic tester). This problem was solved using the example of carbonate production formations of the Magovskoye oil and gas condensate field, which are generally characterized by a complex heterogeneous structure. An analysis of the effectiveness of using a modular dynamic reservoir tester made it possible to clarify the boundaries of permeable rock intervals with an assessment of their saturation. At the same time, working intervals of the geological section were established, which, with standard logging, were interpreted as dense rocks.

Ключевые слова:
модульный динамический испытатель пластов на кабеле, глубинный оптический анализ, месторождения нефти и газа, геофизические исследования, гидродинамические исследования скважин, пластовый флюид, отбор проб.

Важной задачей при контроле разработки месторождений углеводородов является получение данных о фильтрационных характеристиках коллекторов и свойствах флюидов в пластовых условиях. При использовании стандартного каротажа в осложненных условиях низкопроницаемых пластов, слабо консолидированных пород и размытых стволов скважин выполнение замеров пластового давления, отбора проб с детальным анализом свойств флюидов весьма затруднительно. Осуществлено исследование с целью уточнения фильтрационных свойств пород геологического разреза методом гидродинамического каротажа с опробованием пластов испытателем на каротажном кабеле MDT (модульный динамический испытатель). Данная задача решена на примере карбонатных эксплуатационных объектов Маговского нефтегазоконденсатного месторождения, которые в целом характеризуются сложным неоднородным строением. Анализ эффективности использования модульного динамического испытателя пластов позволил уточнить границы проницаемых интервалов пород с оценкой их насыщения. При этом установлены работающие интервалы геологического разреза, которые при стандартном каротаже интерпретируются как плотные породы.

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Introduction

Currently, the calculation of hydrocarbon (HC) reserves and the design of the development of oil and gas fields is carried out on the basis of digital permanent geological and technological 3D models (DPGTM) [1–5]. The basis for constructing a DPGTM is the data interpretation results from geophysical surveys of wells (GSW), a complex of which is necessarily carried out in the open trunk of all drilled wells. The main methodological aspects of constructing a DPGTM are reflected in works [1–3]. At the same time at the stage of geological 3D modeling, according to GSW data, the reservoir properties of rocks are assessed, primarily the coefficients of porosity (K_p), oil saturation (K_s) and permeability (k).

When interpreting GSW data in addition to the number of well-known methodological problems that arise when determining K_p [6–9], the main problem is the difficulty of assessing the filtration characteristics of the formation. According to filtration studies of core in combination with X-ray tomography data [10–14], for complex carbonate reservoirs the relationship between k and Kp is often statistically insignificant which does not allow the geological structure of productive objects in the DPGTM to be reliably represented using well logging data. At the same time in complex reservoir conditions it is recommended to use a full-size core during research [15–17] in combination with well hydrodynamic testing (HDT) data [18–20].

Also drilling wells with core sampling significantly increases the cost of drilling wells. Accordingly, for wells that are drilled without core sampling it is necessary to use additional methods to control the filtration properties of the formation. This paper analyzes the use of a modular dynamic wireline formation tester (MDT) for this task.

Objectives Setting. Materials and Methods

The Modular Dynamic Reservoir Tester (MDT) provides the ability to quickly perform multiple measurements of reservoir pressure (P_r) while also allowing multiple sampling representative deep examples of reservoir fluid. In this case logging hydrodynamic studies (LHD) and sampling on a logging cable (SLC) are performed using both a double packer and a pressure probe. While implementing MDT technology during measuring P_r and testing formations in domestic fields a radial probe "Saturn" is ordinary used along the perimeter of which there are four self-sealing inlet ports located around the circumference at 90° intervals. The holes are isolated from the wellbore by the same inflatable packer which is pressed against the well walls by a sealing surface ensuring uniform fluid selection throughout the entire circumference, significantly reducing the time for testing formations. The main technological limitations of using the method include the size of the well diameter which should not exceed the capabilities of the inflatable elements (packers) as well as the unevenness of the well walls which do not allow hermetically installing the pressure probe [21–23].

WFT/LHD devices allow to obtain reliable data on the Pr distribution over the geological section and determine the nature of study intervals saturation with an assessment of their reservoir properties [24–26] in real time during open hole exploration. Modern configurations of wireline formation testers are equipped with a group of complex analyzers that allow real-time monitoring of the basic properties and composition of the fluid (GOR, hydrocarbon composition, pressure, temperature, electrical resistivity, density, etc.) [27–29].

The using MDT equipment allows studies to be carried out for determining permeability and permeability anisotropy through interval testing, recording pressure drawdown (PDC) and pressure build-up (PBC) curves. The experience of using MDT technology in determining PDC and PBC is described in papers [30–32]. A schematic diagram of the MDT method used in research by Schlumberger is shown in Fig. 1. While processing MDT results, the Schlumberger software named InSitu Pro 3.0.0 is usually used [33].

Papers describe recommendations [34–36] for selection of sampling intervals and data processing of the WFT/LHD methods. In difficult geological and technological conditions with strong bore deviation (including in horizontal wells) mdt studies are recommended to be performed using a drilling tool using TLC (Tough Logging Conditions) technology. It is worth noting that testing a water-saturated reservoir with a two-packer unit with sampling formation fluid allows to obtain valuable information about the properties of formation water [37–39] (temperature, resistivity, formation pressure, salinity), which is necessary in the future while calculating reserves.

The results of WFT/LHD make it possible to estimate reservoir pressures (Pr) of the studied formations with sufficient accuracy. At the same time the experience of conducting mdt generally shows a satisfactory comparison of P_r assessing results according to the LHD data and formation testers in the open hole [40–42].

Thanks to the capabilities of MDT several different productive intervals can be examined and sampled during a single trip. The method allows sampling at minor pressure differences which facilitates obtaining representative samples of formation fluids [43, 44].

Results

In this work the analysing effectiveness of using MDT technology was carried out for the carbonate Bashkirian-Serpukhov and Tournai-Famennian deposits of the Magovskoye oil and gas condensate field.

Research in the conditions of considered deposits was carried out sequentially in two stages:

• firstly, fluid mobility and reservoir pressure were assessed using a pressure probe in promising intervals;

• at the second stage, the intervals which are the most significant for assessing the nature of saturation and taking deep samples, previously selected based on the results of studies with a pressure probe, were studied using an assembly with a double packer. The decision to take a sample was made when a stable degree of formation fluid purification from the drilling fluid filtrate was achieved according to the inflow composition sensors.

Research using MDT technology in the intervals of the Bashkirian-Serpukhovian deposits was carried out on a number of the Magovskoye field domes where oil, oil and gas condensate and gas condensate massifs of productive rocks were installed. The reservoirs for them are represented by porous and fractured limestones and dolomites, overlain by clays from the lower part of the Vereian horizon and dense carbonates from the upper part of the Bashkirian stage. Dolomites are light gray, heterogeneous, unevenly calcareous, porous, cavernous, with brown oil exudates, strong, fractured in areas. The limestones are light gray, fine-grained, finely cavernous, usually with the smell of oil in a fresh fracture.

Hydrodynamic studies using MDT were carried out in two wells where, according to core and GSW data, the main reservoirs are identified in dolomite interlayers with a total reservoir thickness of more than 60 m. The weighted average values of reservoir properties according to GSW data are: K_p = 9.5 %, K_s = 68.28 %, k = 4 mD.

These intervals according to the GSW complex are assessed as oil-saturated. In addition, in the geological section interlayers with a total thickness of 3.3 m were identified with deteriorated reservoir properties according to boundary values, close to the characteristics of reservoirs. There the weighted average characteristics of the reservoir properties are estimated from the GSW as follows: K_p = 6.6%, K_s = 46.6 %, k = 0.9 mD.

The results of using the MDT technology in one of the wells are shown in Fig. 2. Totally 74 standard LHD measurements were carried out with an P_r estimation for 12 measurement intervals. The measured P_r values are in the range from 180.1 to 183.4 atm with fluid mobility values from 0.01 to 11.8 mD/mPa•s. At the same time, according to the LHD results and GSW interpretations depths for testing were selected in order to clarify the nature of reservoir saturation.

The interpretation results in the interval 1990.5–2004.2 m are given in table 1 where it can be seen that the MDT technology makes it possible to evaluate the nature of reservoir saturation with an assessment of the fluid viscosity (μ), K_n and k of the study interval as well as the skin factor (S).

In table Fig. 1 it is shown reservoir intervals where according to well logging interpretation the nature of saturation was not reliably established. At the same time according to GSW the reservoirs were assessed as probably oil-bearing in the interval of 2003.1–2004.2 m, while according to the LHD, an influx of oil with water was obtained in a ratio of 70 to 30 %. In general, a comprehensive interpretation of standard logging and geological testing methods provides the recommendations basis for additional studies of this interval in the column to clarify the position of the oil-water contact (OWC).

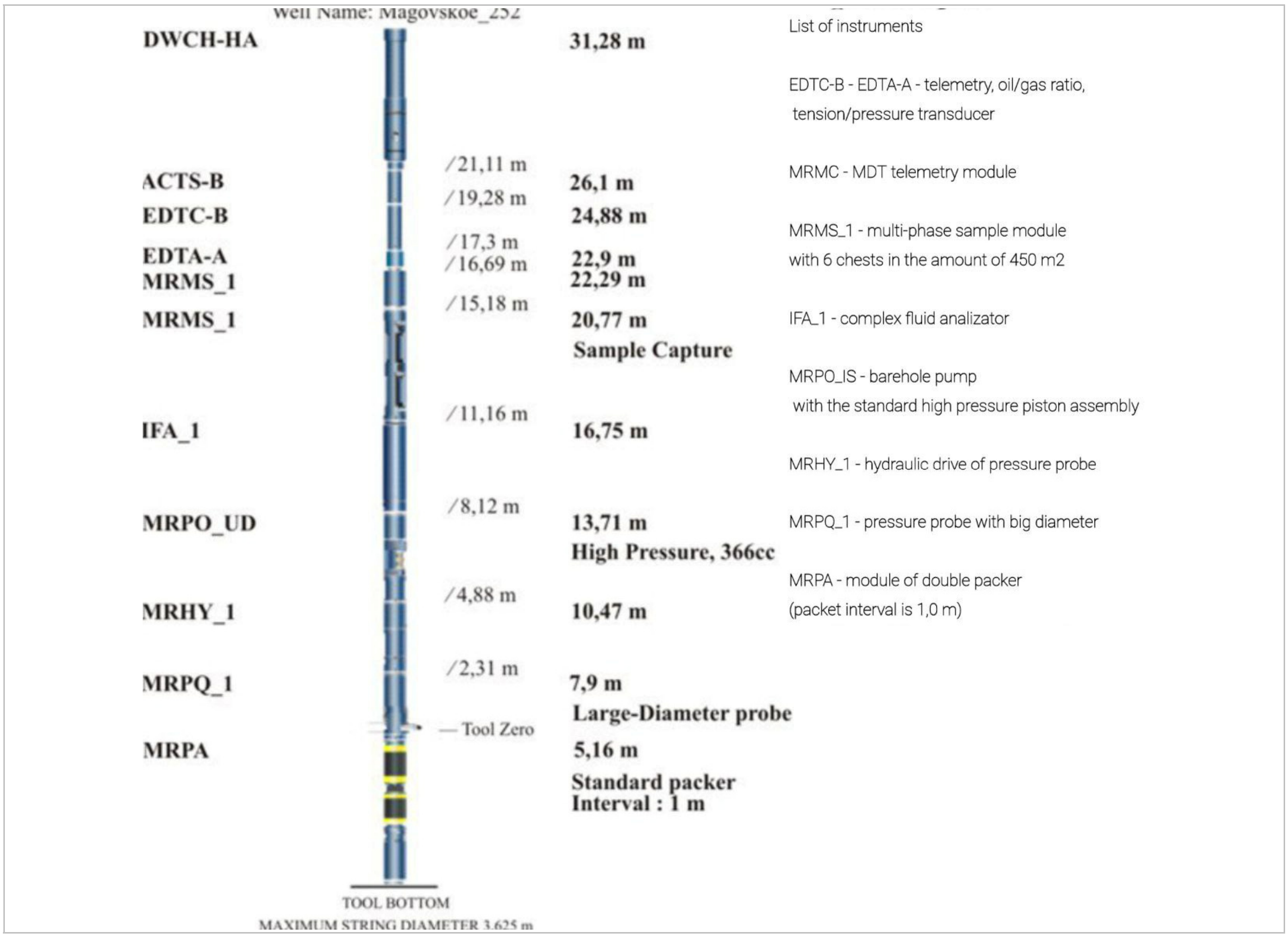

Fig. 1. Layout scheme of MDT method [33]

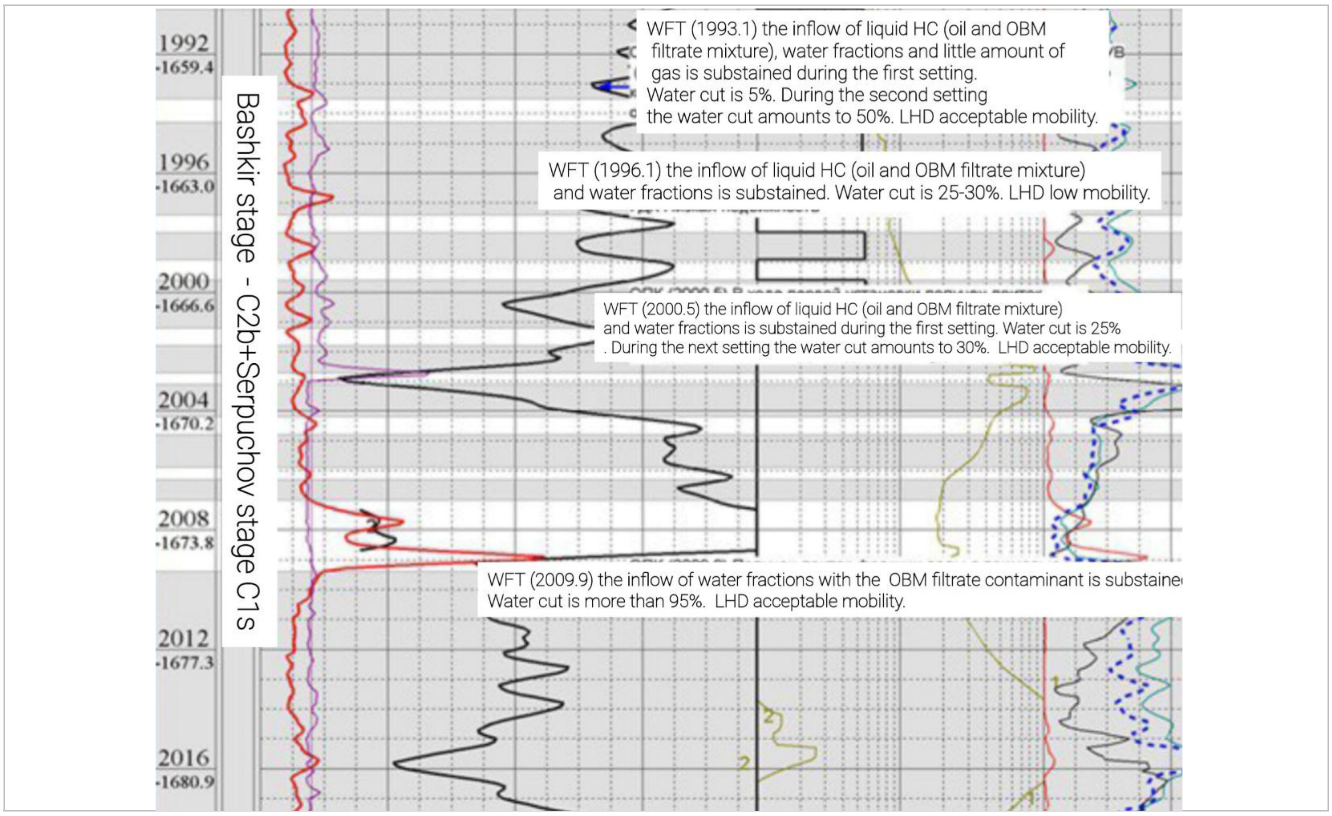

Fig. 2. Graphic representation of the MDT record in one of the wells of the Bashkir-Serpukhov production facility

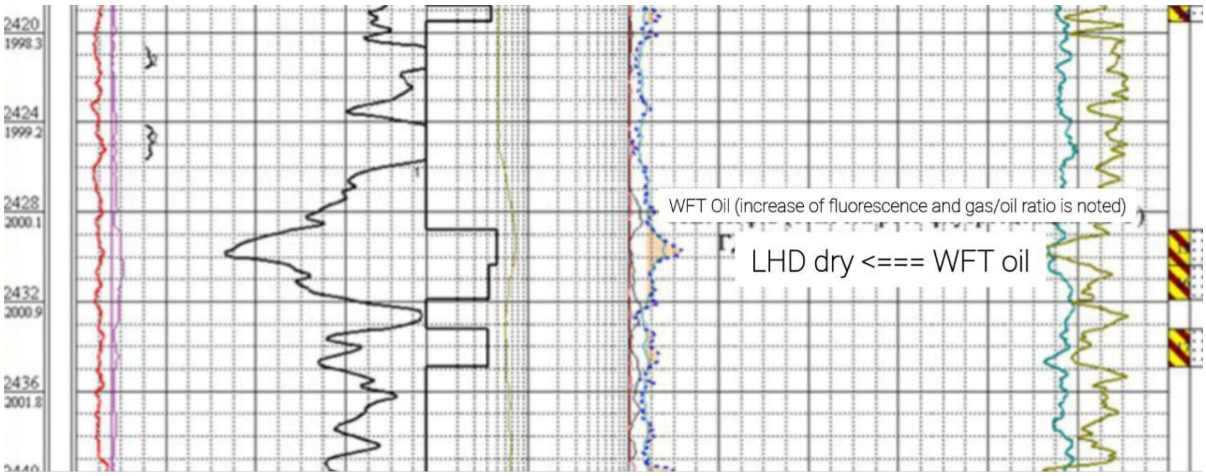

Fig. 3. Graphic representation of an MDT record in one of the wells of the Tournai-Famennian production site

Table 1

Formation characteristics of the Bashkir-Serpukhov production facility
based on the results of using MDT technology

Depth interval, m	Formation pressure, atm	μ, mPa·s	*k*, mD	K_s %	Skin factor *S*, without unit	Fluid content
1990,5–1993,5	180.1	0.69	1.96	59.1	2.0	Oil
1994,3–1997,4	180.6	0.69	40.4	60.8	52.0	Oil
1998,0–1998,9	179.1	0.69	29.6	64.2	38.0	Oil
1999,6–2001,2	183.4	0.69	86.9	55.7	124.3	Oil
2003,1–2004,2	183.2	0.4	–	–	–	Water

Table 2

Formations characteristics of the Bashkir-Serpukhov and Tournais-Famennian production facilities
based on the results of hydrodynamic studies using MDT

Object	Depth interval, m	μ, mPa·c	Formation pressure, atm	*k*, mD	K_s, %	Skin factor, *S*, without unit.	Fluid content
T-Fm	2466.7–2467.0	1.0	204.70	84.1	82.7	543.0	Oil
T-Fm	2468.2–2469.0	1.0	205.18	82.8	82.5	543.0	Oil

Oil and gas condensate deposits on the Magovsky and Raevsky domes, oil deposits on the Yuzhno-Raevsky dome and non-industrial gas condensate deposits on the northern dome of the Yuzhno-Mysinsky uplift are confined to the Tournaisian-Famennian deposits. The reservoirs are characterized as low-porosity, their share in the section is insignificant. According to the core data, the sediments are represented by gray, fine-grained, slightly porous, locally fissured and cavernous limestones.

The results of applying the MDT technology in Tournaisian-Famennian deposits are shown in Fig. 3. A total amount of 59 standard LHD measurements were carried out with an estimate of P_r for 14 section intervals. The measured P_r value was 204.7 atm with fluid mobility values of 24.8 mD/mPa·s.

Based on the results of GSW interpretation no reservoir intervals have been identified in the Tournai-Famennian deposits, while for a number of K_p interlayers was estimated to be in the range of 5–6 %. The interpretation results of hydrodynamic studies using MDT in the interval 2466.7–2469.0 m are given in table 2.

From the data in table 2 it is shown that the use of MDT technology in a dense section according to GSW data made it possible to identify thin oil-saturated reservoir layers with k of the order of 80 mD. In these intervals with a total thickness of 1.1 m the fluid and reservoir characteristics (μ, K_n, S) were also determined.

Conclusion

Thus, as a result of the analysing the MDT technology effectiveness, the reservoirs boundaries with their saturation and qualitative characteristics were clarified. Analysing the effectiveness of using a modular dynamic formation tester made it possible to clarify the boundaries of permeable rock intervals with an assessment of their saturation. At the same time working intervals of the geological section have been established, which are interpreted as dense rocks while standard logging.

It should be noted that in general the MDT method has a relatively low cost of research and significantly complements the results of GSW interpretation. In addition, MDT is a direct method for studying productive formations providing fluid selection with determination of formation saturation (oil, gas, water) which cannot be always performed with sufficient reliability in a carbonate section using standard well logging methods. As a result of the research, the structure of the Bashkir-Serpukhov and Tournai-Famennian productive formations was clarified, that can be used in the DPGTM construction of the Magovskoye oil, gas and condensate field.

References

1. Putilov I.S., Potekhin D.V., Galkin V.I. Mnogovariantnoe 3D-modelirovanie s kontrolem kachestva realizatsii dlia povysheniia dostovernosti geologicheskikh modelei [Multiple 3D modelling with quality surveillance of realizations to increase reliability of geological models]. *Geologiia, geofizika i razrabotka neftianykh i gazovykh mestorozhdenii*, 2015, no. 10, pp. 17-20.
2. Li H., Zhang J. Well log and seismic data analysis for complex pore-structure carbonate reservoir using 3D rock physics templates. *Journal of Applied Geophysics*, 2018, vol. 151, pp. 175-183. DOI: 10.1016/j.jappgeo.2018.02.017
3. Iakupov R.F., Khakimzianov I.N., Mukhametshin V.V., Kuleshova L.S. Ispol'zovanie gidrodinamicheskoi modeli pri sozdanii obratnogo konusanefti v usloviiakh vodoneftianykh zon [Hydrodynamic model application to create a reverse oil cone in water-oil zones]. *SOCAR Proceedings*, 2021, no. 2, pp. 54-61. DOI: 10.5510/OGP20210200496
4. Repina V.A., Galkin V.I., Galkin S.V. Primenenie kompleksnogo ucheta petrofizicheskikh kharakteristik pri adaptatsii geologo-gidrodinamicheskikh modelei (na primere vizeiskoi zalezhi Gondyrevskogo mestorozhdeniia nefti) [Complex petrophysical correction in the adaptation of geological hydrodynamic models (on the example of Visean pool of Gondyrev oil field)]. *Zapiski Gornogo instituta*, 2018, vol. 231, pp. 268-274. DOI: 10.25515/PMI.2018.3.268
5. Beltiukov D.A., Kochnev A.A., Galkin S.V. The possibilities of combining different-scale researches in creating a rock permeability array in a reservoir simulation model of a deposit with a fractured-cavernous type of carbonate reservoir. *IOP Conference Series: Earth and Environmental Science*, 2022, vol. 1021(1), 012027 p. DOI: 10.1088/1755-1315/1021/1/012027
6. Potekhin D.V., Putilov I.S. Primenenie neironnykh setei dlia interpretatsii geofizicheskikh issledovanii skvazhin permokarbonovoi zalezhi Usinskogo mestorozhde-niia nefti [Neural networks use for interpretation of wells geophysical surveys of Permian carboniferous deposit in the Usinsk oil field]. *Geologiia, geofizika i razrabotka neftianykh i gazovykh mestorozhdenii*, 2022, no. 4 (364), pp. 24-27. DOI: 10.33285/2413-5011-2022-4(364)-24-27
7. Galkin C.B., Safin D.K. O vozmozhnosti ispol'zovaniia mnogomernykh statisticheskikh modelei pri otsenke otkrytoi poristosti [On the possibility of using multidimensional statistical models in estimating open porosity]. *Neft' i gaz. Vestnik PGTU.* Perm', 2000, iss. 4, pp. 25-28.
8. Galkin S.V. Vozmozhnosti statisticheskoi otsenki sistematicheskogo zanizheniia opredelenii poristosti po dannym GIS pri ispol'zovanii chastnykh petrofizicheskikh zavisimostei [Possibilities of statistical assessment of systematic underestimation of porosity determinations according to well logging data using partial petrophysical dependencies]. *Geologiia, geofizika i razrabotka neftianykh mestorozhdenii*, 2000, no. 8, pp. 17-20.
9. Zakliuchnov I.S., Putilov I.S. Prognoz kollektorov Padunskogo mestorozhdeniia s ispol'zovaniem usovershenstvovannogo sposoba sopostavleniia seismicheskikh atributov i skvazhinnykh dannykh [Using an improved reservoir prediction method based on seismic attributes and well data comparison for reservoir prediction (Padunskoe oilfield)]. *Geofizika*, 2021, no. 5, pp. 19-23.
10. Shapiro S., Khizhniak G., Plotnikov V., Niemann R., Ilushin P., Galkin S. Permeability dependency on stiff and compliant porosities: a model and some experimental examples. *Journal of Geophysics and Engineering*, 2015, vol. 12, no. 3, pp. 376-385. DOI: 10.1088/1742-2132/12/3/376
11. Pakzad A., Iacoviello F., Ramsey A., Speller R., Griffiths J. et al. Improved X-ray computed tomography reconstruction of the largest fragment of the Antikythera Mechanism, an ancient Greek astronomical calculator. *PLoS ONE*, 2018, vol. 13 (11), e0207430 p. DOI: 10.1371/journal.pone.0207430
12. Efimov A.A., Galkin S.V., Savitckii Ia.V., Galkin V.I. Estimation of heterogeneity of oil & gas field carbonate reservoirs by means of computer simulation of core x-ray tomography data. *Ecology, Environment and Conservation*, 2015, vol. 21 (Nov. Suppl.), pp. 79-85.
13. Efimov A.A., Savitckii Ia.V., Galkin S.V., Shapiro S. Experience of study of core from carbonate deposits by x-ray tomography. *Vestnik Permskogo natsional'nogo issledovatel'skogo politekhnicheskogo universiteta. Geologiia. Neftegazovoe i gornoe delo*, 2016, vol. 15, no. 18, pp. 23-32. DOI: 10.15593/2224-9923/2016.18.3
14. Galkin S.V., Martyushev D.A., Osovetsky B.M., Kazymov K.P., Song H. Evaluation of void space of complicated potentially oil-bearing carbonate formation using X-ray tomography and electron microscopy methods. *Energy Reports*, 2022, no. 8, pp. 6245-6257. DOI: 10.1016/j.egyr.2022.04.070
15. Postnikova O.V., Postnikov A.V., Sival'neva O.V., Olenova K.Iu., Putilov I.S., Potekhin D.V., Saetgaraev A.D. Litologo-petrofizicheskaia neodnorodnost' karbonatnykh rezervuarov Timano-Pechorskoi neftegazonosnoi provintsii [Lithological and petrophysical heterogeneity of carbonate reservoirs of Timan-Pechora oil and gas province]. *Trudy Rossiiskogo gosudarstvennogo universiteta nefti i gaza imeni I.M. Gubkina*, 2021, no. 4 (305), pp. 5-20. DOI: 10.33285/2073-9028-2021-4(305)-5-20
16. Kozyrev N.D., Kochnev A.A. Opredelenie i uchet masshtabnogo effekta kernovogo materila pri geologo-gidrodinamicheskom modelirovanii produktivnykh karbonatnykh rezervuarov [Determination and accounting of the scale effect of core material in geological-hydrodynamic modeling of productive carbonate reservoirs]. Geologiia v razvivaiushchemsia mire: sbornik nauchnykh trudov po materialam XIV Mezhdunarodnoi nauchno-prakticheskoi konferentsii studentov, aspirantov i molodykh uchenykh. Ed. Zorin I.S. Perm', 2021, pp. 214-217.
17. Raznitsyn A.V., Putilov I.S. Razrabotka metodicheskogo podkhoda k vydeleniiu petrofizicheskikh tipov slozhnopostroennykh karbonatnykh porod po dannym laboratorno-go izucheniia kerna [Development of a methodological approach to identifying petrophysical types of complicated carbonate rocks according to laboratory core studies]. *Nedropol'zovanie*, 2021, vol. 21, no. 3, pp. 109-116. DOI: 10.15593/2712-8008/2021.3.2
18. Martiushev D.A., Galkin S.V., Shelepov V.V. Vliianie napriazhennogo sostoianiia gornykh porod na matrichnuiu i treshchinnuiu pronitsaemost' v usloviiakh razlichnykh litologo-fatsial'nykh zon turne-famenskikh neftianykh zalezhei Verkhnego Prikam'ia [The influence of the stress state of rocks on the

matrix and fracturing Permeability in the conditions of various lithologic-facial zones of the Turn-Famen oil deposits of the Upper Kama region]. *Vestnik Moskovskogo universiteta. Geologiia*, 2019, no. 5, pp. 44-52. DOI: 10.33623/0579-9406-2019-5-44-52
19. Martyushev D.A., Yurikov A. Evaluation of opening of fractures in the Logovskoye carbonate reservoir. *Petroleum Research*, 2021, vol. 6 (2), pp. 137-143. DOI: 10.1016/j.ptlrs.2020.11.002
20. Ponomareva I.N., Galkin V.I., Martiushev D.A., Chernykh I.A., Chernyi K.A., Galkin S.V. Statisticheskaia otsenka dostovernosti opredeleniia fil'tratsionnykh parametrov plasta s primeneniem krivykh stabilizatsii davleniia i analiza dobychi v razlichnykh geologo-fizicheskikh usloviiakh [Statistical assessment of the reliability of determining formation filtering parameters using pressure stabilization curves and analysis of production under different geological-physical conditions*]. Geologiia, geofizika i razrabotka neftianykh i gazovykh mestorozhdenii*. Moscow, 2020, no. 11 (347), pp. 63-67. DOI: 10.30713/2413-5011-2020-11(347)-63-67
21. Shakirov A.A. Metod i tekhnologiia GDK-OPK. Perspektivy dal'neishego razvitiia]. [Methods and procedures of wireline formation logging and formation testing. perspectives with their future development]. *Neft'. Gaz. Novatsii*, 2020, no. 3 (232), pp. 40-43.
22. Latypov A.F., Veinkheber P.D., Abdrakhmanova L.G., Karpekin E.A., Blinov V.A., Gordeev Ia.I., Maslov S.O. Primenenie ispytatelei plastov na kabele novogo pokoleniia dlia otsenki kharaktera nasyshcheniia slozhnykh kollektorov Verkhnechonoskogo mestorozhdeniia [The use of new generation wireline formation testers to assess the saturation nature of complex reservoirs of the Verkhnechonoskoye field]. *Nedropol'zovanie XXI vek*, 2021, no. 4 (29), pp. 42-44.
23. Kagan K.G., Samoilenko A.Iu. Opyt primeneniia sovremennykh metodov gidrodinamicheskikh issledovanii skvazhin v otkrytom stvole [Experience in the application of modern methods of hydrodynamic studies of wells in an open hole]. Aktual'nye problemy neftegazovoi otrasli. Volgograd, 2020, pp. 188-196.
24. Bykov E.S., Torin S.V. Otsenka svoistv plastovykh fliuidov na rannikh etapakh razrabotki neftianykh mestorozhdenii s ispol'zovaniem plastoispytatelia [Evaluation of reservoir fluid properties at the early stages of oil field development using a formation tester]. *Aktual'nye voprosy i innovatsionnye resheniia v neftegazovoi otrasli.* Samara, 2021.
25. Diliavirov I.T., Abunagimov M.R., Isiangulov R.U., Mustafin A.M., Zmanovskii V.A., Luk'ianov N.N. Opyt ispol'zovaniia modul'nogo plastoispytatelia dlia resheniia razlichnykh geologicheskikh zadach [Experience of using the modular formation dynamics tester for solving different geological problems]. *Karotazhnik*, 2020, no. 2 (302), pp. 63-77.
26. Shakirov A.A., Danilenko V.N. Sovremennoe sostoianie apparatury i metodiki ispytaniia plastov i otbora priborami na kabele [The current state of equipment and methods for testing formations and sampling with wireline devices]. *Neft'. Gaz. Novatsii*, 2018, no. 2, pp. 46-49.
27. Shakirov A.A., Sharaev A.P. Apparaturno-metodicheskii kompleks priamykh me-todov issledovaniia skvazhin [Instrumental and methodological complex of direct methods of well survey]. *Neft'. Gaz. Novatsii*, 2015, no. 2, pp. 32-34.
28. Rybal'chenko V.V., Sitdikov N.R., Khoshtariia V.N., Vovk N.V., Dmitriev S.E., Ivashin M.D., Svikhnushin N.M. Vozmozhnosti kolichestvennykh otsenok promyslovykh parametrov neftegazovykh zalezhei ispytateliami plastov na kabele [Possibilities of quantitative evaluation of field parameters of oil and gas deposits by wireline formation testers]. *Stroitel'stvo neftianykh i gazovykh skvazhin na sushe i more*, 2016, no. 12, pp. 32-40.
29. Akram Kh., Ashurov V. Obzor gidrodinamicheskikh issledovanii skvazhin v otkrytom i obsazhennom stvole modul'nymi ispytateliami plastov MDT/CHDT [Overview of hydrodynamic studies of wells in open and cased holes with modular formation testers MDT/CHDT]. *Neftegazovoe obozrenie*. Vesna 2005, pp. 30-45.
30. Shakirov A.A. Probootborniki dlia neftegazovykh skvazhin]. [Samplers for oil and gas wells]. *Karotazhnik*, 2019, vol. 7(265), pp. 159-162.
31. Shakirov A.A., Sharaev A.P., Murzakov E.M., Basharova R.M. Razvitie apparatury gidrodinamicheskogo karotazha i oprobovaniia plastov [Development of equipment for hydrodynamic logging and formation testing]. Tver', 2011, no. 5 (203), pp. 202-208.
32. Aigil'din A.L., Amineva G.R., Zubik A.O., Kuchurina O.E. Analiz rezul'tatov issledovanii plastovymi ispytateliami na kabele v usloviiakh slozhnopostroennykh karbonatnykh kollektorov [Analysis of the results of studies by reservoir testers on a cable in the conditions of complex carbonate reservoirs]. *Ekspozitsiia. Neft'. Gaz.* Ufa, 2022, no. 4 (89), pp. 33-37. DOI: 10.24412/2076-6785-2022-4-33-37
33. Sattarov A.I., Mikheev M.L. Perspektivy Rossiiskogo servisa s primeneniem apparatury Schlumberger [Prospects for Russian service using Schlumberger equipment]. Novaia tekhnika i tekhnologii dlia trudnoizvlekaemykh zapasov uglevodorodov. Ufa, 2022, pp. 19-23.
34. Tyshkunov V.V., Maksakov V.A., Osipov D.V. Vydelenie kollektorov po geofizicheskim dannym [Identification of reservoirs by geophysical data]. *Sovremennye problemy lingvistiki i metodiki prepodavaniia na russkom iazyke v vuze i shkole*, 2022, no. 40, pp. 778-783.
35. Srebrodol'skaia M.A. Osobennosti provedeniia karotazha v protsesse bureniia go-rizontal'nykh skvazhin dlia otsenki fil'tratsionno-emkostnykh svoistv gornykh porod [Features of logging while drilling in horizontal wells to estimate reservoir properties]. *Trudy rossiiskogo gosudrastvennogo universiteta nefti i gaza imeni I.M. Gubkina*, 2019, no. 1 (294), pp. 45-57. DOI: 10.33285/2073-9028-2019-1(294)-45-57
36. Shakirov A.A., Gutorov Iu.A. Sovremennyi geofizicheskii informatsionno-kommunikatsionnykh kompleks dlia gidrodinamicheskikh issledovanii kollektorov nefti i gaza [Modern geophysical information and communication complex for hydrodynamic studies of oil and gas reservoirs]. Ufa: Ufimskii gosudarstvennyi neftianoi tekhnicheskii universitet, 2012, 374 p.
37. Belhouchet H., Benzagouta M., Dobbi A., Mazouz E., Achi N., Joelle Duplay, Khodja M. Reservoir compartmentalization and fluid property determination using a modular dynamic tester (MDT): case study of an Algerian oil field. Hal open science, 2021. DOI: 10.1007/s41207-020-00216-5
38. Manish K.L., Viet Hoang Tran, Larry E. Drennan. Challenges and Values of Formation Testing in Tight Sand in Monterey Formation Using Modular Dynamic Tester (MDT). *Online Journal for E&P Geoscientists*, 2015.
39. Costaschuk J., Halverson D., Robertson A. Cross discipline use of the Modular Formation Dynamics Tester (MDT) in the North Sea. *Petrophysicist*, 2021.
40. Belhouchet H., Benzagouta M. Reservoir compartmentalization and fluid property determination using a modular dynamic tester (MDT): case study of an Algerian oil field. *Euro-Mediterranean Journal for Environmental Integration*, 2021. DOI: 10.1007/s41207-020-00216-5
41. Mattax C.C., Dalton R.L. Rezervoir Simulation. SPE, Monograph: Henry L. Daherty Series, 2000.
42. Baouche R., Nedjari A. The use of the Modular Dynamic Tool In petrophysical parameters evaluation: application to the Bir-Berkine reservoirs. Algeria. Department of Geophysic, University of Boumerdes, 2019.
43. Zahid M. MDT job planning and interpretation. *Petrophysicist*, 2021.
44. Dussan V.E.B., Sharma Y. Analysis of the Pressure Response of a Single-Probe Formation Tester. *SPE 160801*, 2002. DOI: 10.2118/16801-PA

Библиографический список

1. Путилов И.С., Потехин Д.В., Галкин В.И. Многовариантное 3D-моделирование с контролем качества реализаций для повышения достоверности геологических моделей // Геология, геофизика и разработка нефтяных и газовых месторождений. – 2015. – № 10. – С. 17–20.
2. Li H., Zhang J. Well log and seismic data analysis for complex pore-structure carbonate reservoir using 3D rock physics templates // Journal of Applied Geophysics. – 2018. – Vol. 151. – P. 175–183. DOI: 10.1016/j.jappgeo.2018.02.017
3. Использование гидродинамической модели при создании обратного конусанефти в условиях водонефтяных зон / Р.Ф. Якупов, И.Н. Хакимзянов, В.В. Мухаметшин, Л.С. Кулешова // SOCAR Proceedings. – 2021. – № 2. –С. 54–61. DOI: 10.5510/OGP20210200496
4. Репина В.А., Галкин В.И., Галкин С.В. Применение комплексного учета петрофизических характеристик при адаптации геолого-гидродинамических моделей (на примере визейской залежи Гондыревского месторождения нефти) // Записки Горного института. – 2018. – Т. 231. – С. 268–274. DOI: 10.25515/PMI.2018.3.268
5. Beltiukov D.A., Kochnev A.A., Galkin S.V. The possibilities of combining different-scale researches in creating a rock permeability array in a reservoir simulation model of a deposit with a fractured-cavernous type of carbonate reservoir // IOP Conference Series: Earth and Environmental Science. – 2022. – Vol. 1021(1). – P. 012027. DOI: 10.1088/1755-1315/1021/1/012027
6. Потехин Д.В., Путилов И.С. Применение нейронных сетей для интерпретации геофизических исследований скважин пермокарбоновой залежи Усинского месторождения нефти // Геология, геофизика и разработка нефтяных и газовых месторождений. – 2022. – № 4 (364). – С. 24–27. DOI: 10.33285/2413-5011-2022-4(364)-24-27
7. Галкин С.В., Сафин Д.К. О возможности использования многомерных статистических моделей при оценке открытой пористости // Нефть и газ. Вестник ПГТУ. Пермь. – 2000. – Вып.4. – С. 25–28.
8. Галкин С.В. Возможности статистической оценки систематического занижения определений пористости по данным ГИС при использовании частных петрофизических зависимостей // Геология, геофизика и разработка нефтяных месторождений. – 2000. – № 8. – С. 17–20.
9. Заключнов И.С., Путилов И.С. Прогноз коллекторов Падунского месторождения с использованием усовершенствованного способа сопоставления сейсмических атрибутов и скважинных данных // Геофизика. – 2021. – № 5. – С. 19–23.
10. Permeability dependency on stiff and compliant porosities: a model and some experimental examples / S. Shapiro, G. Khizhniak, V. Plotnikov, R. Niemann, P. Ilushin, S. Galkin // Journal of Geophysics and Engineering. – 2015. – Vol. 12, № 3. – P. 376–385. DOI: 10.1088/1742-2132/12/3/376
11. Improved X-ray computed tomography reconstruction of the largest fragment of the Antikythera Mechanism, an ancient Greek astronomical calculator / A. Pakzad, F. Iacoviello, A. Ramsey, R. Speller, J. Griffiths [et al.] // PLoS ONE. – 2018. – Vol. 13 (11). – P. e0207430. DOI: 10.1371/journal.pone.0207430
12. Estimation of heterogeneity of oil & gas field carbonate reservoirs by means of computer simulation of core x-ray tomography data / A.A. Efimov, S.V. Galkin, Ia.V. Savitckii, V.I. Galkin // Ecology, Environment and Conservation. – 2015. – Vol. 21 (Nov. Suppl.). – P. 79–85.

13. Experience of study of core from carbonate deposits by x-ray tomography / A.A. Efimov, Ia.V. Savitckii, S.V. Galkin, S. Shapiro // Вестник Пермского национального исследовательского политехнического университета. Геология. Нефтегазовое и горное дело. – 2016. – Т. 15, № 18. – С. 23–32. DOI: 10.15593/2224-9923/2016.18.3
14. Evaluation of void space of complicated potentially oil-bearing carbonate formation using X-ray tomography and electron microscopy methods / S.V. Galkin, D.A. Martyushev, B.M. Osovetsky, K.P. Kazymov, H. Song // Energy Reports. – 2022. – № 8. – P. 6245–6257. DOI: 10.1016/j.egyr.2022.04.070
15. / Литолого-петрофизическая неоднородность карбонатных резервуаров Тимано-Печорской нефтегазоносной провинции / О.В. Постникова, А.В. Постников, О.В. Сивальнева, К.Ю. Оленова, И.С. Путилов, Д.В. Потехин, А.Д. Саетгараев // Труды Российского государственного университета нефти и газа имени И.М. Губкина. – 2021. – № 4 (305). – С. 5–20. DOI: 10.33285/2073-9028-2021-4(305)-5-20
16. Козырев Н.Д., Кочнев А.А. Определение и учет масштабного эффекта кернового материла при геолого-гидродинамическом моделировании продуктивных карбонатных резервуаров // Геология в развивающемся мире: сборник научных трудов по материалам XIV Международной научно-практической конференции студентов, аспирантов и молодых ученых / отв. редактор И.С. Зорин. – Пермь, 2021. – С. 214–217.
17. Разницын А.В., Путилов И.С. Разработка методического подхода к выделению петрофизических типов сложнопостроенных карбонатных пород по данным лабораторного изучения керна // Недропользование. – 2021. – Т. 21, № 3. – С. 109–116. DOI: 10.15593/2712-8008/2021.3.2
18. Мартюшев Д.А., Галкин С.В., Шелепов В.В. Влияние напряженного состояния горных пород на матричную и трещинную проницаемость в условиях различных литолого-фациальных зон турне-фаменских нефтяных залежей Верхнего Прикамья // Вестник Московского университета. Серия 4: Геология. – 2019. – № 5. – С. 44–52. DOI: 10.33623/0579-9406-2019-5-44-52
19. Martyushev D.A., Yurikov A. Evaluation of opening of fractures in the Logovskoye carbonate reservoir // Petroleum Research. – 2021. – Vol. 6 (2). – P. 137–143. DOI: 10.1016/j.ptlrs.2020.11.002
20. Статистическая оценка достоверности определения фильтрационных параметров пласта с применением кривых стабилизации давления и анализа добычи в различных геолого-физических условиях / И.Н. Пономарева, В.И. Галкин, Д.А. Мартюшев, И.А. Черных, К.А. Черный, С.В. Галкин // Геология, геофизика и разработка нефтяных и газовых месторождений. – М., 2020. – № 11 (347). – С. 63–67. DOI: 10.30713/2413-5011-2020-11(347)-63-67
21. Шакиров А.А. Метод и технология ГДК-ОПК. Перспективы дальнейшего развития // Нефть. Газ. Новации. – 2020. – № 3 (232). – С. 40–43.
22. Применение испытателей пластов на кабеле нового поколения для оценки характера насыщения сложных коллекторов Верхнечоноского месторождения / А.Ф. Латыпов, П.Д. Вейнхебер, Л.Г. Абдрахманова, Е.А. Карпекин, В.А. Блинов, Я.И. Гордеев, С.О. Маслов // Недропользование XXI ВЕК. – 2021. – № 4 (29). – С. 42–44.
23. Каган К.Г., Самойленко А.Ю. Опыт применения современных методов гидродинамических исследований скважин в открытом стволе // Актуальные проблемы нефтегазовой отрасли. – Волгоград, 2020. – С. 188–196.
24. Быков Е.С., Торин С.В. Оценка свойств пластовых флюидов на ранних этапах разработки нефтяных месторождений с использованием пластоиспытателя // Актуальные вопросы и инновационные решения в нефтегазовой отрасли. – Самара, 2021.
25. Опыт использования модульного пластоиспытателя для решения различных геологических задач / И.Т. Дилявиров, М.Р. Абунагимов, Р.У. Исянгулов, А.М. Мустафин, В.А. Змановский, Н.Н. Лукьянов // Каротажник. – 2020. – № 2 (302). – С. 63–77.
26. Шакиров А.А., Даниленко В.Н. Современное состояние аппаратуры и методики испытания пластов и отбора приборами на кабеле // Нефть. Газ. Новации. – 2018. – № 2. – С. 46–49.
27. Шакиров А.А., Шараев А.П. Аппаратурно-методический комплекс прямых методов исследования скважин // Нефть. Газ. Новации. – 2015. – № 2. – С. 32–34.
28. Возможности количественных оценок промысловых параметров нефтегазовых залежей испытателями пластов на кабеле / В.В. Рыбальченко, Н.Р. Ситдиков, В.Н. Хоштария, Н.В. Вовк, С.Е. Дмитриев, М.Д. Ивашин, Н.М. Свихнушин // Строительство нефтяных и газовых скважин на суше и море. – 2016. – № 12. – С. 32–40.
29. Акрам Х., Ашуров В. Обзор гидродинамических исследований скважин в открытом и обсаженном стволе модульными испытателями пластов MDT/CHDT // Нефтегазовое обозрение. – 2005. – Весна. – С. 30–45.
30. Шакиров А.А. Пробоотборники для нефтегазовых скважин // Каротажник. – 2019. – Т. 7(265). – С. 159–162.
31. Развитие аппаратуры гидродинамического каротажа и опробования пластов / А.А. Шакиров, А.П. Шараев, Е.М. Мурзаков, Р.М. Башарова // Тверь. – 2011. – № 5 (203). – С. 202–208.
32. Анализ результатов исследований пластовыми испытателями на кабеле в условиях сложнопостроенных карбонатных коллекторов / А.Л. Айгильдин, Г.Р. Аминева, А.О. Зубик, О.Е. Кучурина // Экспозиция. Нефть. Газ. – Уфа, 2022. – № 4 (89). – С. 33–37. DOI: 10.24412/2076-6785-2022-4-33-37
33. Саттаров А.И., Михеев М.Л. Перспективы Российского сервиса с применением аппаратуры Schlumberger // Новая техника и технологии для трудноизвлекаемых запасов углеводородов. – Уфа, 2022. – С. 19–23.
34. Тышкунов В.В., Максаков В.А., Осипов Д.В. Выделение коллекторов по геофизическим данным // Современные проблемы лингвистики и методики преподавания на русском языке в вузе и школе. – 2022. – № 40. – С. 778–783.
35. Сребродольская М.А. Особенности проведения каротажа в процессе бурения горизонтальных скважин для оценки фильтрационно-емкостных свойств горных пород // Труды российского государственного университета нефти и газа имени И.М. Губкина. – 2019. – № 1 (294). – С. 45–57. DOI: 10.33285/2073-9028-2019-1(294)-45-57
36. Шакиров А.А., Гуторов Ю.А. Современный геофизический информационно-коммуникационных комплекс для гидродинамических исследований коллекторов нефти и газа. – Уфа: УГНТУ, 2012. – С. 374.
37. Reservoir compartmentalization and fluid property determination using a modular dynamic tester (MDT): case study of an Algerian oil field / H. Belhouchet, M. Benzagouta, A. Dobbi, E. Mazouz, N. Achi, Duplay Joelle, M. Khodja // Hal open science. – 2021. DOI: 10.1007/s41207-020-00216-5
38. Manish K.L., Viet Hoang Tran, Larry E. Drennan. Challenges and Values of Formation Testing in Tight Sand in Monterey Formation Using Modular Dynamic Tester (MDT) // Online Journal for E&P Geoscientists. – 2015.
39. Costaschuk J., Halverson D., Robertson A. Cross discipline use of the Modular Formation Dynamics Tester (MDT) in the North Sea // Petrophysicist. – 2021.
40. Belhouchet H., Benzagouta M. Reservoir compartmentalization and fluid property determination using a modular dynamic tester (MDT): case study of an Algerian oil field // Euro-Mediterranean Journal for Environmental Integration. – 2021. DOI: 10.1007/s41207-020-00216-5
41. Mattax C.C., Dalton R.L. Rezervoir Simulation. – SPE, Monograph: Henry L. Daherty Series, 2000.
42. Baouche R., Nedjari A. The use of the Modular Dynamic Tool In petrophysical parameters evaluation: application to the Bir-Berkine reservoirs. – Algeria. – Department of Geophysic, University of Boumerdes, 2019.
43. Zahid M. MDT job planning and interpretation // Petrophysicist. – 2021.
44. Dussan V.E.B., Sharma Y. Analysis of the Pressure Response of a Single-Probe Formation Tester // SPE 160801. – 2002. DOI: 10.2118/16801-PA

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