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Features of Physicochemical Properties and Conditions of the Location of Deep Hard-to-Recover Oils

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Abstract

Hydrocarbon deposits occurring at a depth of more than 4.5 km are poorly studied, although they are situated on all continents. This slows down the assimilation of these resources. Analysis of the information from the database of the Institute of Petroleum Chemistry of Siberian Branch of the Russian Academy of Sciences on the physicochemical properties of oil showed that the largest oil reserves are concentrated at depth down to 3000 m. The features of the changes of physicochemical properties of oils were established to depend on the depth of occurrence. It is shown that in different oil basins the density and viscosity of oil decreases with depth. The content of sulphur, resins and asphaltenes decreases with depth, while the content of petroleum gas and fractions increases with depth. The analysis of hydrocarbon occurrence conditions at great depths was carried out. The prospects of oil and gas potential of the deep sediments of oil and gas basins in Russia and Western Siberia, in particular, are evaluated.

Keywords: deep-seated sediments, oil and gas basin, deposits, database, physicochemical properties, occurrence conditions, West Siberian oil and gas basin

INTRODUCTION

Theoretically and practically relevant fundamental investigations are connected with the problem of deep seated oil: substantiation of the possibility to conserve and detect large accumulations of oil at a depth more than 4500 m. Search for hydrocarbons in deeply seated horizons is especially urgent for the goal to enhance the raw material basis of 'old' and developing oil and gas producing centres. However, in spite of the efforts lasting for many years, this task has not yet been carried out in full.

According to [1–6], hard-to-recover resources include oil embedded in geologically complicate or deep seated strata or represented by non-mobile oil. This oil is characterized by relatively low well production rates due to the low productivity of strata, unfavourable conditions of oil occurrence (gas and oil pools, depth more than 4500 m, *etc.*) or anomalous physicochemical properties. Therefore, deep seated oil and gas deposits relate to difficult-to-recover resources.

The regularities of changes in the physicochemical properties of oil with an increase in occurrence depth were studied on the basis of statistical analysis of the information from the Database on physicochemical properties of oil compiled at the Institute of Petroleum Chemistry SB RAS (Tomsk). At present, this Database includes the descriptions of more than 33 570 oil samples from 6350 deposits [7, 8]. The distribution of information in the Database over the depth is represented in Table 1, where the number of oil and gas bearing basins (OGB) and deposits is also indicated. One can see that oil from the shallow and medium-depth occurrences is represented in the Database by the set with the largest number of samples, while the number of samples from deep seated occurrences in the Database is an order of

magnitude smaller, which is the evidence of the urgency of development of hydrocarbon resources from poorly explored deep horizons.

The goal of the present work was to study the regularities of the changes in the physicochemical properties of deep seated oil and the conditions of its locations with an increase in occurrence depth.

THE SPATIAL DISTRIBUTION OF DEEP SEATED OIL

Deep seated oil (at a depth of more than 4500 m) relates to difficult-to-recover raw materials with complicated occurrence conditions. The Database contains 469 oil samples from the depth of more than 4500 m, from 215 deposits of 26 OGB (see Table 1). A large number of deposits with deep seated oil are in several OGB: North Caucasian, West Siberian, Pre-Caspian, Perth, the Gulf of Mexico, and Tarim. The following deposits are distinguished by the deepest wells: Khalakhatang (6640–7070 m), Tuoputay (6400–6750 m), and Aiding (6140–6330 m) in the Tarim basin, Medicine River (6300–6980 m) and Crossfield (6733 m) in the West Canadian basin, Shakh-Deniz (6500–6688 m) in the Southern Caspian basin, Gomes (6050–7022 m) and Lingerna (6560 m) in the Permian basin, Malossa (6250 m) in the Andriatic OGB *etc*. Unique and large-scale deposits are: Urengoyskoye and Samburgskoye (West Siberian OGB), Tengiz, Kashagan, Kalamkas, Asrakhanskoye and Korolevskoye (Pre-Caspian OGB), Bach-Kho (Wung-Tau), Shaz-Deniz (Northern Caucasian OGB) and Pembina (West Canadian OGB).

In Russia, deep seated pools are characteristic mainly of the West Siberian and Northern Caucasian OGB – 33 and 35 deposits, respectively, among which the most distinguished deposits are Khankalskoye (5800 m), Novolakskoye (5650 m), Andreevskoye (5600 m) and Samurskoye (5480 m) from the Northern Caucasian basin, En-Yakhinskoye (8200 m), Mokhtikovskoye (7600 m), Gydanskoye (7000 m), Geologicheskoye (5750 m), Lukyavinskoye (5664 m), Urengoyskoye (5520 m), Nizhnepurskoye (5500 m) and Samburgskoye (5480 m) in the West Siberian OGB. Three deposits in the Toman-Pechora basin (Vostochno-Sarutayuskoye, Vuktylskoye and Kozlayuskoye) have wells within depth range 4520–5090 m. Two deposits in the Volga-Ural OGB (Antipovsko-Balykleyskoe and Zaykinskoye) are distinguished by deep wells.

TABLE 1

Distribution of the information from the Database of the Institute of Petroleum Chemistry SB RAS over the depth of occurrence

Depth of occurrence, m	Number, pc.		
	Samples in the Database	Deposits	Oil and gas bearing basins
0–1000	4238	1548	133
1000–2000	7110	2177	127
2000–3000	6731	1876	110
3000–4500	2491	897	68
Deeper than 4500	469	215	26

PHYSICOCHEMICAL PROPERTIES OF DEEP SEATED DIFFICULT-TO-RECOVER OIL

It is known [7] that oil characteristics differ in average values depending on the vertical arrangement of the pools (Table 2). For instance, the heaviest and most viscous oils occur at a depth down to 1000 m, and then a trend is exhibited for decreased density and viscosity with an increase in the depth: to 0.8389 g/cm^3 at a depth down to 4500 m and to 66 mm^2/s (by a factor of 46), respectively. Oils at a small depth are mainly sulphur-containing, resinous, medium-asphaltene, medium-paraffin, with low gas content. With an increase in depth to 4500 m, a decrease in sulphur content (by a factor of 3), resins (by a factor of 2.4) and asphaltenes (by a factor of 2) is observed, but the concentrations of paraffin and gas content increase (by a factor of 3 and 3.8, respectively). Deep seated oil is light. with increased viscosity, with the high content of paraffins, petroleum gas, with low sulphur, resin and asphaltene content.

The physicochemical properties of deep seated oil are presented in Table 3. One can see that the deep seated oil may be considered as light oil on average, with increased viscosity, high-paraffin, low-sulphur, low-resin, low-asphaltene, with the high content of the fraction with initial boiling point (IBP) 200 °C and a medium content of the fraction with IBP 300 °C. One can see in Tables 2 and 3 that the trends to decreased density, sulphur, resin and asphaltene content is conserved for oil seated deeper than 4500 m. High gas content was revealed in this oil [9–12], which is a complicating factor for oil mining. According to the data shown in Table 3, the average formation temperature in the zone of mining from great depth is higher than 134 °C. According to the information from the Database, the range of for-

TABLE 2

Physicochemical properties of oil occurring at different depths

Depth of occurrence, m	Density, g/cm^3	Viscosity at 20 °C, mm^2/s	Content, mass %				Gas content
			Sulphur	Paraffins	Resins	Asphaltenes	
0–1000	0.9016	3088.25	1.35	3.22	15.58	4.36	65.98
1000–2000	0.8658	310.84	1.39	4.66	12.85	3.67	78.03
2000–3000	0.8389	117.16	0.71	5.45	7.00	1.94	125.09
3000–4500	0.8373	66.39	0.44	9.94	6.43	1.94	253.43

mation temperature variation is 45 to 312 °C (The Gudermesskoye deposit, the Northern Caucasian OGB), which, in turn, may bring technological complications into mining and may cause threat of ecological consequences of mining and development of high-temperature deep seated oil. The formation pressure in deep horizons changes to 104 MPa (which is characteristic of the deposits in the Northern Caucasian OGB). This also points to the problem with the technologies of the development of these resources.

A criterion of the selection of the most promising basins in Russia and adjacent territories was developed in [13] for the search of deep seated accumulations of hydrocarbons on the basis of the data on the thickness of the sedimentary cover at OGB (more than 10 km), substantial residual resources, the high degree of exploration of the upper (2000–4000 m) horizons of the section, the presence of large-capacity traps, the existence of reliable caps providing insulation of the deep lying horizons. It was established [13] that the most promising basin for the search of deep seated pools is the Pre-Caspian OGB, then come the West Siberian and Southern Caspian basins, followed by the Northern Caucasian and the Barents Sea basins, then the Timan-Pechora, Okhotskiy, Volga-Ural, Northern Crimean basins, with the Lena-Tunguska and Lena-Vilyuy basins to close the list.

The physicochemical properties of deep seated oil for the indicated promising OGB with the high potential of deep horizons are to be considered now: the Pre-Caspian, Northern Caucasian and Southern Caspian basins (Table 4). One can see that oil properties differ in average values for different OGB. For instance, oil from the Northern Caucasian basin exhibits the lowest density and low viscosity, it is distinguished by the least content of sulphur, resins, and asphaltenes but increased paraffin content, which is also characteristic of the deep seated oil from the Southern Caspian basin. Pre-Caspian oil,

TABLE 3

Physicochemical properties of deep seated oil

	Number of samples	Average value
Density, g/cm^3	204	0.8371
Viscosity at 20 °C, mm^2/s	90	145.43
Content, mass %:		
sulphur	142	0.47
paraffins	88	6.17
resins	81	5.99
asphaltenes	77	1.65
Fraction, mass %:		
IBP 200 °C	51	31.25
IBP 300 °C	50	53.27
IBP 350 °C	26	62.47
Gas content in oil, m^3/t	38	459.38
Occurrence conditions:		
Formation temperature, °C	154	134.06
Formation pressure, MPa	138	63.09
Porosity of collector, %	59	13.61
Permeability of collector, mdm^2	78	0.11

TABLE 4

Physicochemical properties of deep seated oil from some oil and gas bearing basins (OGB)

Physicochemical parameters	OGB		
	Pre-Caspian	Southern Caspian	Northern Caucasian
Density, g/cm^3	0.8217	0.8415	0.8154
Viscosity at 20 °C, mm^2/s	268.24	20.66	0.99
Content, mass %:			
sulphur	0.51	0.19	0.16
paraffins	4.08	9.10	7.72
resins	5.05	7.80	2.33
asphaltenes	1.07	1.66	0.38
Fraction, mass %:			
IBP 200 °C	33.11	21.36	29.50
IBP 300 °C	51.73	39.16	59.36
IBP 350 °C	60.80	57.40	60.44
Gas content in oil, m^3/t	422.76	–	398

characterized by the increased content of fraction composition and petroleum gas, possesses the highest viscosity but it contains lower amount of paraffins.

The Timan-Pechora and Volga-Ural deep seated oils differ from the world average level (see Table 3) in the content of asphaltenes (the average values are 0.25 and 0.14 %, respectively, the concentration is lower by a factor of 6–11) and resins (2.22 and 2.74 %, respectively, the concentration is 2 times lower).

TABLE 5

Changes in oil occurrence conditions with an increase in depth

Depth of occurrence, m	Formation temperature, °C	Formation pressure, MPa	Porosity, %	Permeability, mdm^2
0–1000	34.80	7.47	22.72	16.17
1000–2000	50.17	16.33	17.80	2.86
2000–3000	82.54	26.59	16.78	0.24
3000–4500	108.22	41.81	14.97	0.19
Over 4500	134.06	63.09	13.61	0.11

CONDITIONS OF THE OCCURRENCE OF DEEP SEATED SEDIMENTS

Collector rocks possessing complicated structures and low permeability are poorly studied at deep locations. This decelerates the development of oil and gas resources in the deep seated sediments of OGB. Geological factors for the formation of deposits in deep horizons remain the same as those for the formation of hydrocarbon accumulations in the upper stages of rocks al a small and medium depth. These factors include the presence of traps, collecting rocks, fluid seals, favourable geochemical and hydrogeological characteristics of the section [14]. However, the characteristics of these factors change with an increase in depth. The reason of substantial differences in geological settings with an increase in depth is first of all substantial densification of rocks at great depths under the action of hydrostatic pressure, which causes changes in the structure and texture of rocks, formation fracturing and generally changes in the structure. Increased tectonic activity at great depths in comparison with the depth of 2000–4000 m also provides substantial differences in the structure of collecting rocks and fluid sealing rocks. Second, the lithological composition of rocks changes. As a result, permeability and cavernosity decrease; the nature of cavernosity changes: it turns from the porous type to fissured-porous, fissured-cavernous. The average values of formation temperature and pressure, porosity and permeability of the collectors depending on occurrence depth according to the data from the Database are shown in Table 5. One can observe a substantial increase in the average formation temperature (by an order of magnitude) and pressure (by a factor of 8.5), a substantial decrease in the porosity (1.6 times) and permeability (two orders of magnitude) of collectors. It was determined that Paleozoic oils comprise the major part (more than 53 %) of the set of deep seated oils under consideration, 1/3 of oil occur in Mesozoic rocks, and about 14 % – in Cenozoic rocks.

Thus, the geological structure of deep horizons is subjected to cardinal changes, so traditional procedures for the predictive evaluation of resources and exploration works become inefficient.

DEEP SEATED OILS OF WEST SIBERIA

The problem of the development of hydrocarbon resources in poorly studied deep horizons is urgent for West Siberia where the major centres of oil and gas production are located, and exploration works are concentrated within the depth range of 3000–4000 m. Industrial development of hydrocarbon resources within this depth range related still to the upper oil and gas bearing stage is technically complicated but does not cause uncertainties in the scientific and methodical respects. Procedures and technologies having a good reputation for the search and exploration of traditional oil and gas deposits are well suitable here.

Deep lying horizons are quite a different subject. It was truly stressed in [15] that questions arise: “Is it reasonable to invest much into search, exploration and development of commercial oil and gas pools that occur in West Siberia at a depth of 4500 to 7000 m and deeper, or is it more reasonable to leave this problem for the future? If yes, what efficient procedures and technologies of search, exploration and development are to be proposed to the industry? It is evident that only rather large deep-seated oil and gas pools characterized by the high density of resources and stable high well yields may be of commercial interest. The mined commercial products should warrant all investment expenses for search, exploration, development and risks”.

As we have mentioned above, 33 deposits with deep seated oil-bearing strata were revealed in the West Siberian OGB. The most substantial resources are considered to be concentrated in the Urengoyskoye, Samburgskoye and Komsomolskoye deposits. Oils are Mesozoic (Jurassic and Triassic) and Paleozoic (Carboniferous, Devonian and Silurian) in almost equal fractions. It was established that deep pools are characterized by high formation temperature (139.3 °C on average) and pressure (78.7 MPa on average), which is higher than the world average parameters of deep seated oil and brings complications into the processes of their development and mining.

Now it is necessary to consider the physicochemical properties of oil from the West Siberian OGB, for which there are 953 samples from 203 deposits occurring at a small depth (down to 2000 m) and 3845 samples from 626 deposits occurring at a medium depth (2000–4500 m). Deep seated samples in the Database are represented by gas pools: 56 samples from 33 gas deposits of the basin; any data on oil from the depth more than 4500 m are absent from the Database. One can see in Table 6 that the properties of oil differ in average values depending on the vertical arrangement of pools. For example, oil from the medium depth, in comparison with oil occurring not deeper than at 2000 m, have lower density, lower viscosity, contain less amount of resins, insignificantly larger amount of sulphur and asphaltenes but higher content of paraffins (by 36 %), fraction composition and petroleum gas.

At present, about 50 parametric and exploration wells have been drilled to a depth of more than 4500 m at the territory of West Siberia. This is too small number for the vast territory of the West Siberian basin. Only two ultradeep research wells were drilled: SG-6 Tyumenskaya (7502 m) and SG-7 En-Yakhinskaya (8250 m), both of them are situated near the Urengoyskoye deposit. It follows from these data that no commercially valuable oil deposits were discovered in this unique oil and gas basin at a depth of more than 4500 m. Several reasons may be indicated.

First of all, the reason is poor geological and geophysical investigation of deep horizons, which involves the absence of reliable regional geological model and adequate notions of the features of oil and gas potential of deep horizons.

Second, there are reasons of technical and technological nature, due to unreadiness of companies to work at great depth within a normal industrial cycle. Unlike for industrially developed upper lying horizons, the working conditions of deep horizons are characterized by rigid thermobaric state and stressed deformation conditions of deep interior, which leads to high rate of accidents, long-term well construction, low quality of sampling and tests.

Third, the known procedures of search and exploration of hydrocarbon pools are imperfect because they are not adapted for working at a great depth. Widely used methods of search and exploration were developed for the upper stage of oil and gas bearing basins and do not take into account the specific features of the structure of deep horizons. As a result, we face mass disconfirmation (by drilling) of geological models and predictions of hydrocarbon resources in deep seated pools [15].

TABLE 6

Physicochemical properties of oil from different depth in the West Siberian OGB

Physicochemical parameters	Small depth of occurrence (down to 2000 m)		Medium depth of occurrence (2000–4500 m)	
	Number of samples	Average value	Number of samples	Average value
Density, g/cm^3	517	0.8531	2033	0.8373
Viscosity at 20 °C, mm^2/s	163	28.76	764	17.68
Content, mass %:				
sulphur	401	0.52	1694	0.61
paraffins	405	3.58	1480	4.87
resins	365	6.60	1328	5.84
asphaltenes	339	1.38	1136	1.48
Fraction, mass %:				
IBP 200 °C	65	24.46	384	25.41
IBP 300 °C	71	43.14	375	45.82
IBP 350 °C	39	49.91	164	56.07
Gas content in oil, m^3/t	145	113.56	810	120.02

TABLE 7

Promising Paleozoic deposits in West Siberia

Deposits	Region
Archinskoye, Verkh-Tarskoye, Vostochnoye, Gerasimovskoye, Elley-Igayskoye, Zapadno-Luginetskoye, Kalinovoye, Luginetskoye, Maloichskoye, Nizhne-Tabaganskoye, Ostaninskoye, Rechnoye, Severo-Ostaninskoye, Severo-Kalinovoye, Selimkhanovskoye, Sovetskoye, Solonovskoye, Tambaevskoye, Urmanskoye, Festivalnoye, Chkalovskoye, Yuzhno-Tabaganskoye, Yuzhno-Tambaevskoye	Tomsk Region
Goreloye, Lovinskoye, Severo-Varyeganskoye, Talinskoye, Tugiyanskoye, Uryevskoye, Yakhlinskoye	Khanty-Mansy Autonomous Area
Bovanenkovskoye, Etypurskoye, Zapolyarnoye, Komsomolskoye, Medvezhye, Novoportovskoye, Severo-Urengoyskoye, Tazovskoye, Urengoyskoye, Yubileynoye, Yamsoveyskoye	Yamal-Nenets Autonomous Area

The major expectations for an increase in oil production in the West Siberian basin are focused on the Paleozoic sediments [16–18]. The list of some deposits with promising accumulations of hydrocarbons in Paleozoic is shown in Table 7.

To conclude the above considerations, the necessity of large-scale works aimed at the regional investigation of the deep interior in West Siberia should be stressed. Unique and the largest deposits are recommended as the first-priority objects for ultradeep parametric drilling: the Yamburgskoye, Urengoyskoye, Zapolyarnoye, Utrenneye and others for which the large promising complexes were revealed and mapped by means of seismic investigations. State programmes for scientific ultradeep drilling are necessary for this purpose. For example, Gazprom Neft has launched Paleozoy project aimed at the development of difficult-to-recover oil including deep seated ones in the Tomsk Region. The Governor, S. A. Zhvachkin, turned to the Ministry of Nature of the Russian Federation for support of the project and conferment of the National title to this project [19].

CONCLUSION

Due to a decrease in the resources of readily available oil in the world, an increase in the fraction of difficult-to-recover resources in the general amount of mined oil is observed at present. Deep seated oil and gas resources will play a special part in the outlooks for an increase in oil production. The features of occurrence conditions and physicochemical properties of oil from deep horizons are described in the work relying on the Database of the physicochemical properties of oil compiled at the Institute of Petroleum Chemistry SB RAS. To develop the promising territories with deep seated oil, it is necessary to take into account the features of deposit formation in deep horizons of oil and gas bearing basins, as well as chemical and component composition of hydrocarbons. The considered problems and outlooks for the development of hydrocarbon accumulations at a great depth in the West Siberian basin outlined the necessity for decision making at the State level.

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