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Specific Features of the Arctic Hard-to-Recover Oil of Siberia

I. G. YASHCHENKO

Institute of Petroleum Chemistry, Siberian Branch, Russian Academy of Sciences, Tomsk, Russia

E-mail: sric@ipc.tsc.ru

Abstract

This paper presents the analysis of the physicochemical properties of unconventional scavenger oils of the Siberian part of the Arctic zone of Russia, which is important in view of the current trends in the development of oil and gas industry. These trends are as follows: an increase in the share of hard-to-recover reserves in the structure of the hydrocarbon resource base, complicated by geological and physical characteristics of reservoirs and special anomalous physical and chemical properties, and shift in the geography of hydrocarbon production to the eastern and Arctic regions of the country with severe climatic conditions. An approach to the study of oil properties based on the classification of hard-to-recover oils is proposed. It is illustrated by the example of the analysis of the features of different types of arctic oils difficult-to-recover in Siberia. The analysis is based on the classification of hard-to-recover oils as a result of literature data compilation. Using the world database on the physicochemical properties of oils, an analysis of the distribution of oils with anomalous properties has been conducted, taking into account increased density, viscosity, high content of sulphur, resins, asphaltenes, solid paraffins, vanadium, nickel, and increased or decreased gas saturation, *etc*. The oil deposits with abnormal occurrence of productive reservoir were found out. The following complicating factors were identified during their development: low-permeable and low-porous reservoirs, reservoirs with abnormally high or low temperature, reservoirs with a burial depth of more than 4500 m, and those occurring in the areas of permafrost distribution, *etc*. The data on more than 4.200 samples of Arctic oils were analysed, which allowed determining special physicochemical properties of hard-to-recover oils deposited in various oil and gas basins of the Arctic zone, especially of its Siberian part. The results of the investigation can be used to develop new technologies and improve the existing methods of oil production and refining under specific Arctic conditions.

Key words: hard-to-recover oil, classification of hard-to-recover oils, oil classification on the basis of physicochemical parameters, physicochemical properties of oil, the Arctic zone of Russia, Siberia

INTRODUCTION

Enormous amounts of hydrocarbons had been extracted from the interior of the Arctic regions of Russia, the USA, Canada and Norway during the past 45 years. The amount extracted in the Arctic zone of Russia (AZR) accounts for about 83.9 % of the total amount [1, 2].

At present, more than 420 oil deposits are known. They are situated in 12 oil-bearing basins of the AZR (Anadyrsko-Navarinskiy, Barentsevo-Karskiy, East Arctic, Yeniseysko-Anabarskiy, West Siberian, Lena-Vilyuiskiy, Lena-Tungusskiy, Penzhinskiy, Pre-Pacific, Timano-Pechorskiy, Ust-Indigirskiy, South Chukotskiy) [3]. Oils from different deposits differ from each other substantially in physicochemical and qualitative parameters. Especially essential difference and diversity of characteristics are expressed by the hard-to-recover oil (HRO) which are considered as the major source of an increase in oil production during the nearest future due to the depletion of the reserves of the most accessible traditional oil. An increase in the amount of HRO production brings about various technological, ecological and economic problems not only for the production but also for oil transportation and processing [4–9]. To solve these problems, it is necessary to study the features of the chemical composition, geological and geographic peculiarities of their occurrence, *etc.*

Some specific features of the physicochemical properties of hard-to-recover oil and the conditions of their occurrence are considered in [10]. A high degree of the complexity of composition and properties of hard-to-recover oils makes the problem of their investigation immeasurably more difficult in comparison with usual oil. So, the necessity arises to develop a classification to the investigation of the features of HRO. In the analysis, we use the classification of hard-to-recover oil proposed in [10] and supplemented by us relying on generalisation of a large number of lilterature data. With the help of this classification, we ranged different kinds of oil, both with anomalous physicochemical properties and with bedding conditions complicated by geological and regional factors (for example, permafrost).

EXPERIMENTAL

Objects of investigation

The object of investigation is hard-to-recover oil. The most valid approach to the determination of hard-to-recover resources was proposed in 1987 by E. M. Khalimov. Relying on this approach, he and N. N. Lisovsky in [10] formulated the basic principles and criteria to attribute oil resources to hard-to-recover ones [10]. As a result of generalisation of these criteria and taking into account the proposals of other specialists [11], a broad list of the major types of hard-to-recover oils had been introduced into consideration. According to [10–17], these types can be conventionally divided into two large groups. The first group will include oils with anomalous properties (for example, with high viscosity or density, high concentration of solid paraffins, with high gas saturation, or with the presence of aggressive components (H_2S, CO_2) in free or dissolved gas in the amounts requiring the use of special equipment during well drilling and oil production, etc). According to [10], the second group of hard-to-recover oil types includes oils with complicated occurrence conditions (embedded in the strata and deposits with geologically complicated structures, in water- and gas-oil zones, in poorly permeable and low-porous collectors, in collectors with anomalously high or low temperature etc.), as well as oils occurring at the territories of permafrost and on sea shelves [13].

To carry out analysis, we used the Petroleum Database compiled at the Institute of Petroleum Chemistry SB RAS as an authoritative source of quantitative information about oil types. Thios Database has been registered at the State Registry of databases and in Rospatent (certificate no. 2001620067) [18, 19]. At present, the Database contains more than 33 430 oil samples from 6344 oil deposits in 190 oil-and-gas bearing basins (OGB) situated at the territories of 94 oil-producing countries.

A list of the major types of hard-to-recover oils is presented in Table 1. The amounts of sampling over different types of oil are also listed on the basis of the information from the indicated Database.

Hard-to-recover oils with anomalous properties are represented in the Database by 25 100 samples, while those with complicated occurrence conditions are represented by 10 500 samples. One can see in Table 1 that the selections of data concerning oils of each of the considered types of hard-to-recover oil are rather representative, which allows uus to obtain statistically valid analysis results.

Methods of investigation

The methods of statistical analysis and data classification for the investigation of the features of hard-to-recover oil and the methods of geoinformation systems for the spatial analysis of the data on their physicochemical properties and occurrence conditions in different OGB and the AZR.

RESULTS AND DISCUSSION

Analysis of the arrangement of hard-to-recover oils in the Arctic

According to the information from the Database, more than 420 deposits are situated in the AZR within the boundaries of the Barentsevo-Karskiy, East Arctic, Yeniseysko-Anabarskiy, West Siberian, Lena-Vilyuiskiy, Lena-Tungusskiy, Penzhinskiy, Pre-Pacific, Timano-Pechorskiy, Ust-Indigirskiy, South Chukotskiy OGB. The largest number of the Arctic deposits are located in the West Siberian basin – 299, 79 – in the Timano-Pechorskiy OGB, 27 – in the Yeniseysko-Anabarskiy basin, 7 – in the Lena-Tungusskiy OGB, while

TABLE 1

Characteristics of different types of hard-to-recover oils according to the information present in the Database

Types of hard-to-recover oil	Sampling amount
Oils with abnormal properties	
Heavy (density more than 0.88 g/cm^3)	7769
Viscous (viscosity more than 35 mm^2/s at 20 °C)	4419
High-sulphur (sulphur content more than 3 mass %)	1091
High-resinous (resin content more than 13 mass %)	2461
High-paraffin (paraffin content more than 6 mass %)	2760
With high gas saturation (more than 500 m^3/t)	150
With low gas saturation (less than 200 m^3/t)	4995
With high hydrogen sulphide content (more than 5 %)	143
The same, vanadium (more than 0.003 mass %)	698
» nickel (more than 0.007 mass %)	209
High-asphaltenous (asphaltene content more than 10 mass %)	465
Oils in deposits with difficult bedding conditions	
Wakly permeable collectors (менее 0.05 mdm^2)	2278
Collectors with low porosity (less than 8 %)	378
Deep bedding (deeper than 4500 m)	469
In the discontinuous-continuous cryolite zone (Russia)	2467
In the insular cryolite zone (Russia)	3126
Stratal temperature above 100 °C	1326
The same, below 20 °C	504

the Barentsevo-Karskiy and Pre-Pacific basins contain 4 deposits each.

Among oil deposits at the territories of the indicated oil-and-gas bearing basins, it is necessary to stress the presence of unique and resource-rich deposits: Pakhtusovskoe in the Barentsevo-Karskiy basin, Urengoyskoe, Russkoe, Severo-Komsomolskoe, Sutorminskoe, Vankorskoe, Samburgskoe, Novoportovskoe and others in the West Siberian basin, Naulskoe, Vozeyskoe, Layavozhskoe, Kharyaginskoe, Yaregskoe, Medynskoe-More and others in the Timano-Pechorskiy basin, Baykalovskoe in the Yeniseysko-Anabarskiy basin, Olenekskoe in the Lena-Tungusskiy basin etc.

Oil of the AZR attracts attention of the specialists of both oil-producing and oil-processing complexes. In this connection, the goal of the work is to study the features of the physicochemical properties and occurrence conditions of hard-to-recover oil in the Arctic zone, especially in its Siberian part. It is known that Siberia geographically includes the territories of West, East Siberia, and the Far East. Therefore, the Siberian Arctic sector includes the oil-and-gas bearing territories of the Yeniseysko-Anabarskiy, West Siberian, Lena-Vilyuiskiy, Lena-Tungusskiy, Pre-Pacidic basins, while the Barentsevo-Karskiy and Timano-Pechorskiy OGB relate to the European part of the Arctic sector.

The quantitative characterisation of the Arctic HRO is presented in Table 2 on the basis of the information from the Database. It is shown that the most numerous deposits in the AZR are those with high-paraffin and heavy oil, the least numerous are the deposits with high hydrogen sulphide and nickel content in oil, and the latter deposits are situated only in the Timano-Pechorskiy basin. Oils from low-porous collectors are small in number. they were revealed only in 6 deposits of the West Siberian and Timano-Pechorskiy OGB. It sho0uld be stressed that only a small number (less than 10) of the deposits with high-sulphur, high-asphaltene and gas-depleted oil was established in the Arctic zone.

Analysis of the features of the physicochemcial properties of hard-to-recover oil in the Arxtic zone of Siberia

Oil-and-gas bearing basins of the Arctic are distinguished by the large resources of heavy and viscous oil [20, 21]. There are 75 deposits of this kind in the AZR (see Table 2). In this situation, 36 deposits belong to the Siberian Arctic, while the major resources of heavy and viscous oil are concentrated in the West Siberian basin. The deposits that may be considered as unique and large include: Russkoe, Severo-Komsomolskoe, Novoportovskoe, Komso-

TABLE 2

Distribution of deposits with HRO in the Arctic zone

Oil types	Number of samples	Number of deposits in oil-and-gas bearing basins
Heavy (density higher than 0.88 g/cm^3)	325	75 deposits: 5 – Yeniseisko-Anabarskiy OGB, 29 – West Siberian OGB, 2 – Lena-Tungusskiy OGB, 39 – Timano-Pechorskiy OGB
Viscous (viscosity more than 35 mm^2/s at 20 °C)	117	47 deposits: 4 – Yeniseisko-Anabarskiy OGB, 10 – West Siberian OGB, 1 – Lena-Tungusskiy OGB, 32 – Timano-Pechorskiy OGB
High-sulphur (sulphur content more than 3 mass %)	16	9 deposits: 1 – Yeniseisko-Anabarskiy OGB (Yuzhno-Tigyasnskoe), 1 – West Siberian OGB (Samburgskoe), 1 – Lena-Tungusskiy OGB (Olenekskoe), 6 – Timano-Pechorskiy OGB
High-resinous (resin content more than 13 mass %)	43	25 deposits: 3 – Yeniseisko-Anabarskiy OGB, 4 – West Siberian OGB, 1 – Lena-Tungusskiy OGB, 3 – Pre-Pacific OGB, 14 – Timano-Pechorskiy OGB
High-asphaltenous (asphaltene content more than 10 mass %)	13	10 deposits: 1 – Yeniseisko-Anabarskiy OGB (Yuzhno-Tyaginskoe), 1 – West Siberian OGB (Severo-Komsomolskoe), 1 – Lena-Tungusskiy OGB (Olenekskoe), 1 – Pre-Pacific OGB (Izmennoe), 6 – Timano-Pechorskiy OGB
High-paraffin (paraffin content more than 6 mass %)	302	82 deposits: 2 – Yeniseisko-Anabarskiy OGB, 39 – West Siberian OGB, 3 – Pre-Pacific OGB, 38 – Timano-Pechorskiy OGB
With high gas saturation gas content in oil more than 500 m^3/t)	15	9 deposits in the West Siberian OGB
With low gas saturation (gas content in oil less than 200 m^3/t)	306	52 deposits: 32 – West Siberian OGB, 1 – Pre-Pacific OGB, 19 – Timano-Pechorskiy OGB
With high hydrogen sulphide content (more than 5 %)	2	2 deposits in Timano-Pechosrkiy OGB – Pomorskoe and Severo-Gulyaevskoe
The same, vanadium (more than 0.003 mass %)	39	18 deposits: 1 – Lena-Tungusskiy OGB (Olenekskoe), 17 – Timano-Pechorskiy OGB
» nickel (mmore than 0.007 mass %)	15	6 deposits in Timano-Pechorskiy OGB
In weakly permeable collectors (less than 0.05 mdm^2)	47	25 deposits: 22 – West Siberian OGB, 3 – Timano-Pechorskiy OGB
In low-porous collectors (less than 8 %)	6	6 deposits: 2 – West Siberian OGB, 4 – Timano-Pechorskiy OGB
Deep bedded (deeper than 4500 m)	52	25 deposits: 24 – West Siberian OGB, 1 – Timano-Pechorskiy OGB
Situated in the zone of continuous permafrost	2810	117 deposits: 4 – Barentsevo-Karskiy OGB, 27 – Yeniseisko-Anabarskiy OGB, 60 – West Siberian OGB, 7 – Lena-Tungusskiy, 3 – Pre-Pacific OGB, 16 – Timano-Pechorskiy OGB
With high stratal temperature (above 100 °C)	75	27 deposits in West Siberian OGB
With low stratal temperature (below 20 °C)	29	12 deposits: 4 – Yeniseisko-Anabarskiy OGB, 7 – West Siberian OGB, 1 – Timano-Pechorskiy OGB

molskoe, Vyngapurovskoe, Zapadno-Messoyakhskoe, Tazovskoe in the West Siberian basin and Olenekskoe in the Lena-Tungusskiy basin.

One can see in Table 3 that the physicochemical properties of heavy and viscous oils do not demonstrate significant differences. The characteristics of viscous oils are slighly higher than the corresponding characteristics of heavy oils except for density, sulphur and vanadium content. According to our classification [3, 22, 23], these kinds of oil relate to the class of heavy ones (heavy oils considered in the present communication belong to the subclass of superheavy ones), highly viscous (viscosity from 100 to 500 mm^2/s), medium-sulphur (sulphur content from 0.5 to 1 mass %), medium-paraffin (with paraffin content 1.5–6 mass %), medium resinous (resin content 8–13 mass %) and low-asphaltene (asphaltene content up to 3 mass %) and depleted of nickel. The indicated specific features of heavy and viscous oils can be significant during oil processing.

The properties of high-sulphur, high-paraffin, high-resinous and high-asphaltene oils are presented in Table 4. It has been established previ-

TABLE 3

Physicochemical properties of heavy and viscous oils in Siberian Arctic

Parameters	Viscous oils (viscosity at 20 °C more than 35 mm^2/s)	Heavy oils (density more than 0.88 g/cm^3)
Density, g/cm^3	0.9174	0.9238
Viscosity at 20 °C, mm^2/s	284.92	210.15
» at 50 °C, mm^2/s	60.35	59.28
Sulphur content, mass %	0.50	0.62
Chilling temperature, °C	−27.90	−30.35
Paraffin content, mass %	2.79	2.07
» resins, mass %	9.96	9.84
» asphaltenes, mass %	1.64	1.61
Gas content, m^3/t	–	–
Coking, mass %	2.67	3.02
Content of vanadium, mass %	0.0009	0.0031
» nickel, mass %	0.0005	0.0005

ously (see Table 2) that the amount of high-sulphur and high-asphaltene oils in the Arctic zone of Siberia is not large. These kinds of oil are present in the following deposits: Yuzhno-Tigyuanskoe (the Yeniseysko-Anabarskiy OGB), Samburgskoe and Severo-Komsomolskoe (West Siberian OGB), Olenekskoe (Lena-Tungusskiy OGB) and Imennoe (Pre-Pacific OGB).

The largest number of deposits contain high-paraffin oil. A leader in the number of such deposits is the West Siberian basin (48 %) (see Table 2). Oil kinds with the highest sulphur content are those from the Samburgskoe (sulphur content 9.2 mass %) and Olenekskoe (4.9 mass %) deposits, while oil kinds with the highest resin content are those from the Yuzhno-Tigyanskoe (Pre-Pacific OGB, resin content 35.0 mass %), Olenekskoe (32.1 mass %) and Izmennoe (24.2 mass %) deposits. The highest asphaltene content was detected in oil from the Yuzhno-Tigyanskoe deposit (14.5 mass %), and the highest paraffin content was detected in the oil from the Izmennope (paraffin content 28.0 mass %), Bovanenkovskoe (West Siberian OGB, 25.7 mass %) and Verkhne-Telekayskoe (Pre-Pacific OGB, content 23.7 mass %) basins.

One can see in Table 4 that high-sulphur oils possess the highest density and viscosity, which allows us to consider them as superheavy and highly viscous oil.

The physicochemical properties of oil with increased gas saturation are presented in Table 5. This oil type is represented by West Siberian oils from 9 deposits of the Yamal-Nenetz autonomous area (Vyngapurovskoe, Vyngayakhinskoe, Ety-

TABLE 4

Physicochemical properties of high-sulphur, high-resinous, high-asphaltenous and high-paraffin oils of Siberian Arctic

Parameters	High-sulphur (more than 3 mass %)	High-resinous (more than 13 mass %)	High-asphaltenous (more than 10 mass %)	High-paraffin (more than 6 mass %)
Density, g/cm^3	0.9570	0.9022	0.9275	0.8429
Viscosity, at 20 °C, mm^2/s	237	157.35	237	9.44
» at 50 °C, mm^2/s	–	55.50	–	6.31
Chilling temperature, °C	–	−28.75	–	4.42
Sulphur content, mass %	4.85	1.07	1.93	0.16
» paraffins, mass %	–	7.29	3.89	9.48
» resins, mass %	31.39	20.73	27.46	3.52
» asphaltenes, mass %	12.87	6.80	16.86	0.48
Gas content, m^3/t	–	–	–	228.17
Coking, mass %	–	–	–	0.84
Content of vanadium, mass %	0.025	0.0004	–	0.00007
» nickel, mass %	–	0.0005	–	0.00004

TABLE 5

Physicochemical properties of Arctic Siberian oils with high gas saturation

Physicochemical parameters	Average values
Density, g/cm^3	0.7854
Viscosity at 20 °C, mm^2/s	3.73
Chilling temperature, °C	−7.00
Sulphur content, mass %	0.46
» paraffins, mass %	5.42
» resins, mass %	3.56
» asphaltenes, mass %	0.55
Gas content, m^3/t	892.51
Coking, mass %	0.42
Content of vanadium, mass %	0.0001
» nickel, mass %	0.00005

Purovskoe, Markovskoe, Novogodnee, Sever-Gubkinskoe, Sutorminskoe, Urengoiskoe, and Kharampurskoe deposits). The deposits with unique resources are Sutorminskoe and Urengoyskoe deposits, other listed deposits are treated as large ones. These oils mainly occur in the strata of the Lower Jurassic age with the depth from 2309 m (Sutorminskoe deposit) to 2939 m (Kharampurskoe deposit). As average, these oils are very light, with negative chilling temperature, low-viscous. According to their chemical properties, they are low-sulphur, low-resinous, low-asphaltenous, medium paraffin, with the high content of oil gas and low content of heavy metals and aggressive components (carbon dioxide and hydrogen sulphide). Oil from Vyngapurovskoe deposit (1670 m^3/t) and Vyngayakhinskoe deposit (1640 m^3/t) exhibit the highest saturation with gas.

The major characteristics of oils with low gas saturation are listed in Table 6. The majority of them occur in the West Siberian OGB at the territory of the Yamal-Nenetz AA. The number of deposits with the same kind of oil in the Siberian part of the Arctic accounted for more than 61 %, and only one deposit, namely Verkhne-Telekayskoe one, is situated in the Pre-Pacific basin. Oils occur at a depth down to 1100 m, and in the majority of cases. they are confined to the Mesozoic sediments. Paleozoic deposits occur in Urengoyskoe, Sutorminskoe, Vyngayakhinskoe, Vyngapurovkoe, Muravlenkovskoe deposits and so on.

Deposits with the high content of vanadium, nickel and hydrogen sulphide in oil were not detected in the Siberian Arctic zone. As a rule, such deposits occur in the European part of the Arctic, in the Timano-Pechorskiy OGB.

As has been already mentioned above, HRO comprises oils of productive objects with the stratal geological-physical characteristics complicating oil production, namely high or low stratal temperatures, low porosity and permeability of collectors, deep occurrence. According to the results of the analysis of the features of hard-to-recover oils, 27 deposits of the West Siberian OGB have been established at the territory of the Yamal-Nenetz AA; these deposits belong to the type of oil with high stratal temperature.

These oils are mainly confined to the Jurassic sediments, while three samples from the Urengoyskoe, Evoyakhinskoe and Yaraynerskoe deposits belong to Paleozoic sediments. “Hot oil” occurs

TABLE 6

Physicochemical properties of Arctic Siberian oils with low gas saturation

Physicochemical parameters	Average values
Density, g/cm^3	0.8467
Viscosity at 20 °C, mm^2/s	6.41
» at 50 °C, mm^2/s	3.59
Chilling temperature, °C	−3.86
Sulphur content, mass %	0.54
» paraffins, mass %	3.51
» resins, mass %	4.97
» asphaltenes, mass %	1.69
Gas content, m^3/t	81.10
Coking, mass %	2.44
Content of vanadium, mass %	0.0003
» nickel, mass %	–

TABLE 7

Physicochemical properties of Arctic oils with high stratal temperatures

Physicochemical parameters	Average values
Density, g/cm^3	0.8044
Viscosity at 20 °C, mm^2/s	6.69
Sulphur content, mass %	0.09
» paraffins, mass %	7.41
» resins, mass %	4.03
» asphaltenes, mass %	0.60
Gas content, m^3/t	–
Coking, mass %	1.95
Content of vanadium, mass %	0.0001
» nickel, mass %	0.00005
» carbon dioxide, mass %	0.80

from medium depth (starting from 2770 m, Vyngayakhanskoe deposit) to large depth (more than 4500 m). Deep-seated deposits include Bovanenkovskoe, Geologicheskoe, Zapolyarnoe, Malyginskoe, Medvezhye, Semakovskoe, Shtormovoe, Urengoyskoe, Yamburgskoe and Yubileynoe deposits, characterized by the maximal depth (5400–5480 m). Evoyakhinskoe, Urengoyskoe, Samburgskoe and Yubileynoe deposits contain the strata with the highest temperatures (up to 150 °C). The average values of physicochemical characteristics of the considered HRO are presented in Table 7. One can see that oils with the high stratal temperature ("hot oil") is characterised by low density (from 0.7700 to 0.8429 g/cm^3) and viscosity, have negative low chilling temperature. According to the content of sulphur (0.01–0.17 mass %), resins (2.05–7.00 mass %) and asphaltenes (0.50–0.70 mass %), as average, these oils belong to low-sulphur, low-resinous and low-asphaltenous oils, while with respect to paraffin content they are high-paraffin oils (the limits of paraffin content are 2.78–12.11 mass %). Oil of the Zapadno-Tarkosalinskoe deposit is distinguished by the highest paraffin content (9.76 and 12.11 mass %) and by the minimal content of sulphur, resins, and asphaltenes: 0.05, 2.05 and 0.60 mass %, respectively.

In the Arctic zone of Siberia, 11 deposits with low stratal temperature were revealed (their total number is 12 in Table 2), among them 4 deposits belong to the Yeniseysko-Anabarskiy basin (Dzhangodskoe, Messoyakhskoe, Nizhnekhetskoe, and Nordvigskoe) and 7 deposits are West Siberian (Bovanenkovskoe, Nakhodkinskoe, Neytinskoe, Russkoe, Semakovskoe, Ust-Chaselskoe and Yuzhno-Tambeyskoe deposits). The strata with the lowest temperature are located in the Yeniseysko-Anabarskiy OGB – the stratal temperature varies from 1 to 12 °C. The physicochemical properties of oil from low-temperature strata are presented in Table 8.

Oil with low stratal temperature is characterised by increased density (from 0.7800 to 0.9428 g/cm^3) and viscosity (72.80–424.85 mm^2/s). This is how their characteristics differ from those of oils from high-temperature strata. Oils have negative low chilling temperature. As far as sulphur content (0.06–1.72 mass %) and asphaltene content (0.50–0.70 mass %) are concerned, as average, these oils belong to low-sulphur and low-asphaltene, resin content is increased (varying within the range 1.31–17.07 mass %). In general, oils belong to the class of "medium-resinous oil", while with respect to paraffin content they are

TABLE 8

Physicochemical properties of Arctic oils from low-temperature strata

Physicochemical parameters	Average values
Density, g/cm^3	0.8871
Viscosity at 20 °C, mm^2/s	248.83
Chilling temperature, °C	−37.50
Sulphur content, mass %	0.47
» paraffins, mass %	1.42
» resins, mass %	9.66
» asphaltenes, mass %	0.65
Gas content, m^3/t	–
Coking, mass %	2.67
Content of vanadium, mass %	0.0027
» nickel, mass %	0.0010
» carbon dioxide, mass %	0.35

low-paraffin oils (0.50–4.20 mass %), which forms their difference from the "hot oil". It should be stressed that the probability of the deposition of asphaltene-resin-paraffin sediments in low-temperature beds on the deep-well pumping equipment, well walls and in the bottomhole formation zone is many times larger in comparison with conventional oil, which leads to a decrease in well production rates and the efficiency of pumping equipment, a decrease in overhaul life, and the period between purification cycles.

One can see in Table 2 that in the AZR there are 24 deposits in West Siberia in which the productive deposits are situated at a depth below 4500 m. The deposits unique in their resources are Sambuirgskoe and Urengoyskoe, large deposits are Evoyakhinskoe, Komsomolskoe, Pyakyakhinskoe, Yamburgskoe, and Yarudeyskoe. These deposits are mainly gas condensate or gas pools.

Let us consider oils related to the Arctic deposits in the zone of continuous permafrost. AS one can see in Table 2, the amount of the information in the Database is about 3000 descriptions of oil samples from 114 deposits of six OGB: Barentsevo-Karskiy, Yeniseysko-Anabarskiy, West Siberian, Lena-Tungusskiy, Timano-Pechorskiy basins. It should be stressed that more than half of the Arctic deposits belong to the West Siberian OGB (51.3 %). The average values of the physicochemical characteristics of the HRO type under consideration are presented in Table 9. It is demonstrated that the physicochemical properties of oil are substantially dependent on basin type. For example, oils in the Lena-Tungusskiy basin are heavy 9with the density more than 0.88 g/cm^3), Oils of the Yeniseysko-Anabarskiy basin are of

TABLE 9

Physicochemical properties of the Arctic oils from the continuous permafrost zone

Physicochemical parameters	Average value				
	Siberian part of the Arctic			European part of the Arctic	
	Yeniseisko-Anabarskiy	West Siberian	Lena-Tungusskiy	Barentsevo-Karskiy	Timano-Pechorskiy
Density, g/cm^3	0.8567	0.8192	0.8847	0.7921	0.8763
Viscosity at 20 °C, mm^2/s	101.85	38.06	31.08	1.40	1008.53
Chilling temperature, °C	−27.67	−25.76	−58.00	−54.00	3.56
Sulphur content, mass %	0.80	0.20	1.45	0.04	1.43
» paraffins, mass %	2.36	4.27	0.95	–	7.30
» resins, mass %	10.81	4.05	11.58	–	7.09
» asphaltenes, mass %	5.20	0.62	5.58	–	3.41
Gas content, m^3/t	–	161.89	–	–	85.48
Coking, mass %	5.36	1.56	–	–	1.37
Content of vanadium, mass %	–	0.00034	0.0277	0.00001	0.0051
» nickel, mass %	–	0.00020	0.0066		0.0099
» carbon dioxide, mass %	0.63	0.82	–	0.36	0.74
» hydrogen sulfide, mass %	–	0.56	–	–	2.09

medium density, and oils of the West Siberian OGB are light. In the European part of the Arctic, oils are related as average to extremely light ones (Barentsevo-Karskiy OGB) or to medium (Timano-Pechorskiy OGB). With respect to viscosity, oils of the Timano-Pechorskiy OGB correspond to super-viscous oils, those of the Yeniseysko-Anabarskiy basin are highly viscous, oils from the West Siberian basin are oils with increased viscosity, those from the Lena-Tungussky OGB are of medium viscosity, while oils of the Barentsevo-Karskiy OGB are low-viscosity oils. Positive chilling temperature is characteristic of oils from the Timano-Pechorskiy OGB. With respect to sulphur content, the Arctic oils of the Barentsevo-Karskiy and West Siberian basins are characterised as low-sulphur (less than 0.5 mass %). The highest sulphur content was established in oil from the Lena-Tungusskiy basin (1.45 mass %). Oils of the Timano-Pechorskiy OGB belong to high-paraffin oils (paraffin content higher than 6 mass %). The content of resins and asphaltenes is minimal in oils from the West Siberian basin, and maximal in the oil of the Lena-Tungusskiy OGB.

Relying on the data shown in Table 9, we may conclude that the Arctic hard-to-recover oils of Siberia are heavier on average than European Arctic oils but less viscous and with lower paraffin and nickel content. Siberian Arctic oils are distinguished by a higher content of resins, asphaltenes, oil gas, vanadium, and increased coking behaviour.

CONCLUSION

New results of the investigation of physicochemical properties of hard-to-recover oils in the Siberian part of the Arctic zone of Russia are presented in the paper. The analysis was carried out using an enormous array of data on oil properties obtained from the Database of the Institute of Petroleum Chemistry SB RAS. The amount of sampling was 4200 oil samples. The total array of data on the Arctic hard-to-recover oils under study was divided into sub-arrays during analysis. These sub-arrays included HRO samples of different classification types with anomalous physicochemical properties and complicated geological-physical characteristics of the strata. For each data sub-array, the average values of the physicochemical were determined; their comparison allowed us to reveal the specific features of the properties of HRO types under consideration for the Arctic territories.

Analysis of the information from the Database showed that the Arctic oils are accommodated in 10 oil-and-gas bearing basins of Russia and are characterised by a broad range of the variation of physicochemical properties. The largest reserves of hard-to-recover oils, especially heavy, viscous and high-paraffin ones, are present in the West Siberian OGB. The absolute majority of HRO, for which the production is complicated by such factors as high gas content (more than 500 m^3/t), high stratal temperature (above 100 °C) and bedding depth more than 4500 m, are concentrated in the Siberian part of the Arctic. The geo-spatial analysis of the arrangement of HRO may be used to determine the outlooks and directions of the development of oil-processing and petrochemical complexes in the Arctic regions of the country.

It is known that oil transportation along oil-trunk pipelines is accompanied by mixing the oils from different deposits with different physicochemical characteristics. Mixing with hard-to-recover oils inevitably leads to a substantial change of the qualitative parameters of the resulting mixture and affects a decrease in the cost of commercial oil, In this connection, the information presented in this paper may be used to optimise the routes of transportation of hard-to-recover oils.

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