INTERNATIONAL JOURNAL OF
ENERGY AND ENVIRONMENT

Volume 5, Issue 5, 2014 pp.611-618

Journal homepage: www.IJEE.IEEFoundation.org

Phisical and chemical properties and thermobaric conditions of occurrence of hard-to-recover oils

I.G. Yashchenko, Y.M. Polishchuk

Institute of Petroleum Chemistry, Siberian Branch of Russian Academy of Sciences, 4, Akademichesky Ave., 634021, Tomsk, Russia.

Abstract
The criteria necessary to classify oils as hard-to-recover oil reserves are determined. The distribution of viscosity, heavy, paraffin and highly resin oils is analyzed in terms of their reserves. The features of the physic-chemical properties of these oils are studied under various conditions of their occurrence and formation temperatures. The results obtained could be used to solve practical issues in the oil sector.

Keywords: Hard-to-recover oils; High-viscosity oils; Heavy oils; Paraffin oils; Highly resin oils; Physical and chemical properties of oils; Conditions of occurrence; Formation temperature; Reservoir pressure; Gas content in oil.

1. Introduction

Regularities of spatial distribution and characteristics of physical and chemical properties of oils were considered in [1-4]. Currently, the world has witnessed the growth of the share of hard-to-recover oils in the total balance due to the depletion of readily available oils. The oils in complex geological formations and deposits or those containing low-mobility oils (e.g., high-viscosity, high-paraffin oils) are classified as hard-to-recover reserves. They are characterized by relatively low flow rates due to low reservoir productivities, unfavorable conditions of oil occurrence (gas and oil deposits at the depths more than 4,500 meters, etc.) or anomalous physical and chemical properties. Currently, however, systematic materials on the properties of such oils in the literature is extremely insufficient. In this regard, the aim of our work was the consideration of physical and chemical properties of hard-to-recover oils and features of the conditions of their occurrence.

2. About hard-to-recover oils

The most reasonable approach to the differentiation of hard-to-recover reserves was proposed by Khalimov in 1987. Purtova and coauthors of [5] made a list of the main criteria for differentiation of hard-to-recover reserves, according to which the such oil reserves are characterized by their specific properties and conditions of their occurrence, namely:

(1) oil reserves possessing anomalous physical and chemical properties (high viscosity and density and high content of paraffins, asphaltenes and resins);
(2) oil reserves in low permeability reservoirs and oil-water and oil-gas zones;
(3) oil reserves with high gas saturation (more than 200m^3/m) or with dissolved and/or free gas containing aggressive components (hydrogen sulfide, carbon dioxide) in the amounts requiring the use of special equipment for well-drilling and oil production;

(4) oil reserves occurring at great depths (below 4,500m);
(5) oil reserves with the reservoir temperature of 100°C and higher or less than 20°C (due to the little difference between the low reservoir temperature and the pour point of wax and resins);
(6) oil reserves with a high degree of water cut (to 75 - 80%).

Recent years have seen an incresed production of hard-to-recover oils with anomalous physical and chemical properties, i.e. paraffin, resin, viscosity and heavy oils. An investigation of these oils requires the development of the respective EOR methods, which in turn makes it necessary to identify patterns of their spatial distribution and to analyze the changes in their physico-chemical properties that depend on the geological and thermobaric conditions of their occurrence. The development of new technologies for production and transportation of oils with anomalous physical and chemical properties and improvement of the available processes require that new data on the properties and conditions of occurrence of hard-to-recover oils be obtained.

The reserves of heavy and viscosity oils are several times higher than those of readily available low-viscosity oils (810 and 162 billion tons, respectively) and represent a raw material source for the oil sector of Russia and other oil-producing countries of the world [6-10]. The development of deposits of viscosity oils is therefore receiving an increasing attention. To date, the average annual total production of these oils in the world is approaching 500 million tons and the cumulative production exceeds 14 billion tons. The most abundant resources of heavy and viscous oil are located in Canada and Venezuela. Mexico, the United States, Russia, Kuwait; China also possess significant heavy oil reserves. On the territory of Russia, the reserves of oil with a viscosity higher than 35 mm^2/s account for 7.3 billion tons oil and most of them are concentrated in the Komi Republic, Tatarstan, and in the Tyumen region. Paraffin crude oils [11, 12], whose viscosity and high pour point are controlled by the high paraffin content (more than 6%) make a considerable fraction in the total reserves of viscous oils. The percentage of paraffin oils is also significant and accounts for more than 25% of all world oils. In particular, 19% of oil fields on the territory of the West Siberian oil-gas basin contain paraffinic oils.

The investigations requiring an analysis of numerous literature sources need the data on physical properties and chemical composition of the global oils and on the geological characteristics of oil bearing basins. A large body of information has been accumulated in the data base on physical and chemical oil properties [13] of the Institute of Petroleum Chemistry, SB RAS (Tomsk). Therefore this data base was used as a source of information on hard-to-recover oils.

The data base includes more than 22,000 oil samples from 191 oil and gas basins of the world, most are those of Eurasian continental oils from 106 oil and gas basins and 4,064 oil fields located in 58 countries. The general characteristics of the data base are presented in Table 1. Being constantly developed and improved, the database is enriched with new data on the physical, chemical and geochemical properties of oils, their geographical location, geological modes of occurrence and formation temperature and pressure. Table 1 offers a description of the continental distribution of the database information.

Table 1. Data distribution by continents

Geography	Data base sample	Number of oil-gas bearing basins	Number of oil fields
Australia, New Zealand and Oceania	152	11	86
Africa	532	15	294
Eurasia	20,629	106	4,064
North and Central America	1,631	38	899
South America	428	21	256

The global database on physical and chemical properties of oils currently contains 5,104 heavy oil samples, 2,510 samples of viscous oil (with a viscosity higher than 35mm^2/s), 2,327 paraffin oil, and more than 2,000 resin oil samples (more than 13 % resin). More detailed characteristics of this information are presented in Table 2.

3. Generalized classification of oils by their physical and chemical parameters

To investigate the physical and chemical properties of hard-to-recover types of oils having anomalous physical and chemical properties and those with properties conditioned by anomalous modes of occurrence, we have developed a generalized classification of oils (Tables 3 and 4).

Table 2. Characteristics of database information on the oils with anomalous properties

Class of oil	Data base sample	Number of oil-gas bearing basins	Number of oil fields
Heavy (density > 0.88 g/cm^3)	5,104	117	1,637
Viscous (viscosity at 20 °C > 35 mm^2/s)	2,510	63	821
Resin (resin content >13 %)	2,030	52	684
Paraffin (paraffin content > 6 %)	2,327	58	800

Table 3. Classification of oils by their density and viscosity

Index	Class of oil		Limits of variation
Density (g/cm^3)	very light oil		< 0.80
	light oil		0.80÷0.84
	medium-density oil		0.84÷0.88
	heavy	higher-density oil	0.88÷0.92
		extra heavy crude oil	0.92÷0.96
		bituminous oil	> 0.96
Viscosity at 20 °C, (mm^2/s)	low-viscosity oil		< 10
	medium-viscosity oil		10 ÷35
	viscous	higher-viscosity oil	35÷100
		high-viscosity oil	100÷500
		extremely-high-viscosity oil	> 500

Table 4. Classification of oils by chemical components

Chemical component, wt%	Class of oil		Limits of variation
Sulfur content, wt%	low sulphur (sweet crude) oil		< 0.5
	medium sulphur oil		0.5÷1
	sulfurous oil		1÷3
	high-sulphur (sour) oil		> 3
Resin content, wt%	low-resin oil		< 8
	medium-resin oil		8÷13
	resin oil	moderately resin	13÷20
		highly resin	20÷30
		extremely resin	> 30
Asphaltene content, wt%	low-asphaltene oil		< 3
	medium-asphaltene oil		3 ÷10
	high-asphaltene oil		> 10
Paraffin content, wt%	low-paraffin oil		< 1.5
	medium-paraffin oil		1.5÷6
	paraffin oils	moderately paraffin	6÷ 10
		highly paraffin	10÷20
		extremely paraffin	> 20
Low-boiling fraction 200 °C, wt%	oils with low fraction-200		< 20
	oils with medium fraction-200		20 ÷30
	oils with high fraction-200		> 30
Low-boiling fraction 350 °C, wt%	oils with low fraction-200		< 25
	oils with medium fraction-350		25÷50
	oils with high fraction-350		50÷75
	oils with extremely high fraction-350		75÷100

4. Analysis of oil distribution by classes

Figure 1 shows the diagrams of distribution of oil types under study by classes in terms of their density, viscosity and content of resins and paraffin. As can be seen from Figures 1a and b, the amount of oil types (light, medium, and heavy oils and low-viscosity, medium-viscosity, and viscous oils) are almost equally distributed by classes, i.e. light, medium density, low viscosity and medium viscosity oils comprise more than 66% of the total sampling. Heavy and viscous oil account for slightly more than 33% of the total sample, and resinous and paraffin oils account for less than 30% in the total sample (Figures 1c and d).

Here we investigate the distribution of hard-to-recover oil reserves (heavy, viscosity, paraffin, and resin) in the Volga-Ural, West Siberian, and Timan-Pechora oil and gas bearing basins (in what follows referred to as Volga-Ural, West Siberian, and Timan-Pechora oil-gas-bearing basins, respectively) as the main Russian oil producing regions. Table 5 shows the distribution of information from the data base for these three basins. These data indicate that the most abundant reserves of viscous, heavy, paraffin, and resin oils are located in Western Siberia; the Volga-Ural basin possesses rich reserves of viscosity, heavy, and resin oils, while the Timan-Pechora basin has concentrated reserves of paraffin oils. The largest number of fields with hard-to-recover oils is located in the Volga-Ural oil-producing regions and the lowest – in the Timan-Pechora basin.

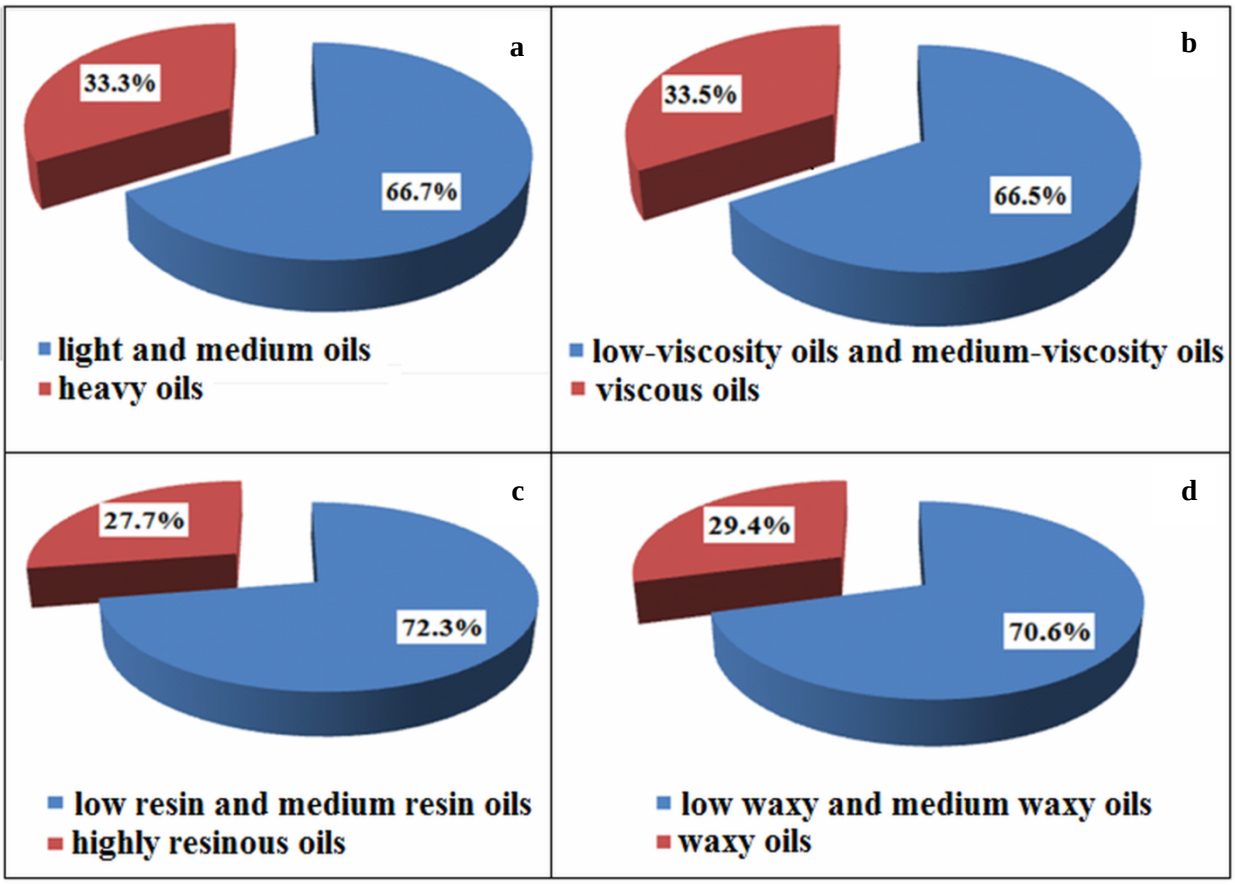

Figure 1. The distribution of the number of deposits by density (a), viscosity (b), content of resin (c) and paraffin (d)

5. Features of the physic-chemical properties of hard-to-recover oils

As already mentioned above, the hard-to-recover oils also include those with a gas factor above 200 m^3/t. The database contains 348 samples of these oils from 255 oil fields of 44 basins. They are distributed over the continents as follows: one – in Australia, 3 – in Africa, 20 – in America and the rest 20 – in Eurasia. Most deposits with high gas content are located in the Volga-Ural (81 deposits), 10 deposits – in the Lena-Tunguss, and 7 deposits each in Western Canadian, Pre-Caspian and Timan-Pechora basins. The physic-chemical properties of these oils are presented in Table 6. It is evident that, according to

Tables 3 and 4, these oils belong to the light, low viscosity, low sulfur, moderately paraffin, and low asphaltene oils.

Table 5. Hard-to-recover oils in the main oil-gas bearing basins of Russia

Statistical data	Oil-gas bearing basins		
	Volga-Ural	West Siberian	Timan-Pechora
Viscous oils			
Number of samples	1,263	157	104
Number of oil fields	362	45	42
Russian oil reserves, %	33.46	37.06	14.30
Heavy oils			
Number of samples	1,787	378	270
Number of oil fields	453	120	60
Russian oil reserves, %	38.35	40.70	9.85
Paraffin oils			
Number of samples	322	449	95
Number of oil fields	140	136	34
Russian oil reserves, %	16.26	40.46	42.50
Resin oils			
Number of samples	1,103	133	66
Number of oil fields	301	58	24
Russian oil reserves, %	45.87	36.46	9.79

Table 6. Physical and chemical properties of crude oils with high gas content (above 200m^3/t)

Physic-chemical parameters	Database sample	Mean value
Density g/cm^3	326	0.83
Viscosity at 20 ºC, mm^2/s	148	7.21
Sulfur content, wt%	248	0.38
Paraffin content, wt%.	173	6.23
Resin content, wt%	104	5.30
Asphaltene content, wt%	126	0.82
Low-boiling fraction 200 °C, wt%	23	31.60
Low-boiling fraction 300 °C, wt%	23	48.28
Gas content in oil, m^3/t	348	346.19
Thermobaric conditions of occurrence		
Reservoir temperature, °C	241	85.88
Reservoir pressure, MPa	232	32.54

The presence of sulfur dioxide also impedes oil production due to the increased environmental hazard, which requires the use of special equipment for well drilling and oil production when the concentration of sulfur dioxide in the oil is higher than 5%. The database comprises 79 samples of oils containing sulfur dioxide gas from 55 oil fields of 19 basins. The physical and chemical properties of these oils are presented in Table 7. It is evident from Table 8 that the oils belong to medium density, high viscosity, sulfurous, medium paraffin, medium asphaltene and moderately resin classes.

The main criteria for differentiation of hard-to-recover reserves are the oil reservoir temperatures above 100°C or below 20°C. The database contains 838 samples of in-reservoir oils at the temperatures higher 100°C from 483 oil fields of 47 basins. Their physic-chemical properties are presented in Table 8. It implies that these oils belong to the light, medium viscosity, low sulfur, low resin and low asphaltene but moderately paraffin classes.

The data base contains 318 samples of oils occurring in low-temperature reservoirs (< 20 ºC) from 181 deposits of 35 basins. The most of oil deposits characterized by low reservoir temperature are located in the Volga-Ural basin (81 deposits), the Lena-Tunguss basin (10 deposits) and in Western Canadian, Pre-Caspian and Timan-Pechora basins (7 deposits each). Their physical and chemical properties are

presented in Table 9. It is evident from Table 9 that these oils belong to the high-density, extremely high-viscosity, sulfur, medium paraffin, moderately resin, medium asphaltene and low gas content oil classes.

Table 7. Physic-chemical properties of crude oils with high sulfur gas content (above 5%)

Physic-chemical parameters	Database sample	Mean value
Density, g/cm^3	23	0.8767
Viscosity at 20 ºC, mm^2/s	10	49.33
Sulfur content, wt%	19	2.18
Paraffin content, wt%	13	4.05
Resin content, wt%	12	14.56
Asphaltene content, wt%	11	6.23
Gas content in oil, m^3/t	15	109.97
Thermobaric conditions of occurrence		
Reservoir temperature, °C	27	74.75
Reservoir pressure, MPa	30	31.81

Table 8. Physical and chemical properties of in-reservoir oils at the temperature above 100°C

Physic-chemical parameters	Database sample	Mean value
Density, g/cm^3	432	0.8251
Viscosity at 20 ºC, mm^2/s	155	12.03
Sulfur content, wt%	237	0.36
Paraffin content, wt%	228	9.85
Resin content, wt%	214	5.36
Asphaltene content, wt%	203	1.27
Low-boiling fraction 200 °C, wt%.	75	29.41
Low-boiling fraction 300 °C, wt%.	64	49.10
Gas content in oil, m^3/t	117	163.63
Thermobaric conditions of occurrence		
Reservoir temperature, °C	838	119.40
Reservoir pressure, MPa	665	38.31

Table 9. Physical and chemical properties of in-reservoir oils at the temperature lower than 20 °C

Physic-chemical parameters	Database sample	Mean value
Density, g/cm^3	221	0.8855
Viscosity at 20 ºC, mm^2/s	165	12,929.34
Sulfur content, wt%	137	1.46
Paraffin content, wt%	126	3.87
Resin content, wt%	112	14.52
Asphaltene content, wt%	106	3.98
Low-boiling fraction 200 °C, wt%.	24	18.75
Low-boiling fraction 300 °C, wt%.	24	33.13
Gas content in oil, m^3/t	104	36.82
Thermobaric conditions of occurrence		
Reservoir temperature, °C	318	15.37
Reservoir pressure, MPa	267	10.04

A comparison of the data from Tables 8 and 9 has shown that oil properties are strongly controlled by the formation temperature. The highest quality indicators are exhibited by the oils occurring in high-temperature reservoirs.

Deep-seated oils (below 4,500m) are also hard-to-recover reserves. There are 354 samples from 180 deposits of 24 basins in the data base. An analysis of their physical and chemical properties presented in Table 10 has revealed that in general they can be classified as light, high-viscosity, medium-sulphur,

medium-paraffin, low-resin, low-asphaltene oils with a high content of low-boiling (200°C) fraction and average content of low-boiling (300°C) fraction. These oils are characterized by a high content of oil gas, which is also complicates oil production.

Table 10. Physical and chemical properties of oils from deep-lying strata (more than 4,500m)

Physic-chemical parameters	Database sample	Mean value
Density, g/cm^3	153	0.8377
Viscosity at 20 ºC, mm^2/s	72	79.15
Sulfur content, wt%	104	0.52
Paraffin content, wt%	66	5.92
Resin content, wt%	59	5.91
Asphaltene content, wt%	62	1.81
Low-boiling fraction 200 °C, wt%.	47	32.14
Low-boiling fraction 300 °C, wt%.	32	46.57
Gas content in oil, m^3/t	9	263.24
Thermobaric conditions of occurrence		
Reservoir temperature, °C	77	117.48
Reservoir pressure, MPa	77	66.73

6. Conclusion

Currently, production of hard-to recover reserves increases due to depletion of readily available oils in the whole world. Here we have identified the criteria for classification of oils as hard-to-recover reserves. Using a global database on physical and chemical properties of oils, we have analyzed the distribution of viscous, heavy, paraffin and highly resin oils in terms of the volume of their reserves. In order to specify the physical and chemical properties of these oils as a function of the conditions and the depth of their occurrence and the reservoir-temperature differences, a generalized classification of oils by their density, viscosity and chemical composition has been developed. The results obtained can be used to develop new methods of enhanced oil recovery, to improve the available technologies, to optimize the transportation of oils with anomalous physical and chemical properties, and to solve a number of related oil-sector problems.

References

[1] Polishchuk Yu.M., Yashchenko I.G. Possible correlation between crude oil chemical composition and reservoir age. Journal of Petroleum Geology. 2006, Vol.29, 2, 189-194.

[2] Polishchuk Yu.M., Yashchenko I.G. Phisico-chemical properties of oils: statistical analysis of spatial and temporal changes. Novosibirsk: Izd-vo of SB RAS, Filial ”Geo”. 2004. – 109 p. [in Russian].

[3] Resource assessment of oil and gas in oil-gas-systems of the world / Eds. K.A. Kleschev, G.F. Ulmishek. - Moscow, VNIGNI. 2008. – 352 p. [in Russian].

[4] Lurier M., Schmidt F. Oil. On the discussion of the origin. Sulfur and metal contents as genetic characteristics. - Saarbrucken: LAP LAMBERT Academic Publishing GmbH & Co. KG, 2012. - 292 p. [in Russian].

[5] Purtova I.P., Varichenko A.I., Shpurov I.V. Hard-to-Recover Oil Reserves. Terminology. Problems and the State of their Development in Russia. Nauka and TEK. 2011, 6, 21-26 [in Russian].

[6] Yakutseni V.P., Petrova Yu.E., Sukhanov A.A. Dynamics of the Share of the Relative Content of Hard-to-Recover Oil Reserves in Balance Reserves. Neftegazovaya Geologiya. 2007, 2, 1-11. www.ngtp.ru [in Russian].

[7] Maksutov R., Orlov G., Osipov A. Development of High-Viscosity Oil Reserves in Russia. Technologies of TEK. 2005, 6, 36-40 [in Russian].

[8] Vartivarian D., Andrawis H. Delayed coking schemes are most econo-mical for heavy-oil upgrading. Oil & Gas Journal. 2006, 6, 52–56.

[9] James G. Speight. The Desulfurization of Heavy Oils and Residua, Second Edition, Revised and Expanded, Laramie, Wyoming, 1999. – 458 p.

[10] Polishchuk Yu.M., Yashchenko I.G. Spatial and temporal changes of density and chemical composition of heavy oils of Eurasia. International Journal of Energy and Environment. 2011, 2, Issue 4, 717-722.
[11] Yashchenko I.G., Polishchuk Yu.M. Physical, Chemical and Rheological Properties of Paraffin Oils. Oil and Gas (Almaty). 2011, 5(65), 59-68 [in Russian].
[12] Yashchenko I.G. Spatial Distribution of Paraffin Oils and their Physical and Chemical Properties. Vestnik TSK Rosnedra. 2011,1, 40-46 [in Russian].
[13] Polishchuk Yu.M., Yashchenko I.G., Kozin E.S., An V.V. Database on the composition and physic-chemical properties of oil and gas (DB OG). Official bulletin of the Russian Agency for Patents and Trademarks. 2001, 3, 340-341 [in Russian].

Yury Polishchuk Professor, Principal researcher of Scientific research information center, Institute of Petroleum Chemistry, Siberian Branch of Russian Academy of Sciences, Tomsk, Russia. Education – Tomsk Politechnical University (1960), Tomsk, Russia, Post-graduate studentship (1963) at Tomsk University of Control Systems and Radioelectronics (TUCSR), Tomsk, Degree of Candidate of Sciences (1966) in TUCSR, Degree of Doctor of Sciences (1985) in Institute of Radiotechnics and Electronics of Russian Academy of Sciences, Moscow, Russia.
E-mail address: yuri@ipc.tsc.ru, yupol@uriit.ru, Yu_Polishchuk@ugrasu.ru

Irina Yashchenko PhD, Head of Scientific research information center, Institute of Petroleum Chemistry, Siberian Branch of Russian Academy of Sciences, Tomsk, Russia, Education – Tomsk Politechnical University (1986), Tomsk, Russia, Degree of Candidate of Sciences (2003) in Tomsk Politechnical University, Tomsk, Russia.
E-mail address: sric@ipc.tsc.ru

