УДК 662.276.53(571.12) doi: 10.24028/gzh.0203-3100.v41i1.2019.158862

Hard-to-recover reserves of Yugra oil (West Siberia)

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Received 9 November 2018

У 2017 р. на частку Югри припадало 43,0 % загальноросійського видобутку нафти, в абсолютних одиницях — 235,3 млн т, що менше на 3,9 млн т, ніж у 2016 р., і на 43,1 млн т — ніж у 2007 р. Основний об'єкт розробки — шельфові пісковики неокому. В Югрі зосереджено 44 % прогнозних ресурсів Росії категорії D_1, тобто ресурсів у відкладах і на територіях з доведеною нафтоносністю. Ключовим завданням для Югри є запобігання зниженню видобутку нафти та його стабілізація. Цього можна досягти завдяки активному залученню у розробку важкодобувних запасів нафти. Проаналізовано критерії таких запасів, можливості і результати залучення їх у розробку в умовах родовищ Югри. Це поклади нафти з аномальними фізико-хімічними властивостями, підгазові зони покладів, відклади пласта $АВ_1^{1-2}$ типу "рябчик", ачимовська товща, тюменська світа, породи доюрського комплексу і баженовська світа. Лише за трьома комплексами (ачимовським, баженовським і тюменським) приріст видобутку нафти в 2017 р. дорівнював майже 4 млн т, що можна порівняти з темпами зниження видобутку в цілому на Югрі. Початкові геологічні ресурси баженовського комплексу оцінено в 11 млрд т, видобувні ресурси — в 3,1 млрд т. Першочергове джерело стабілізації видобутку нафти в Югрі — залучення в розробку важкодобувних запасів ачимовського і тюменського комплексів. Можливе зростання видобутку таких запасів доюрського комплексу, його річний видобуток становить 2—3 млн т. Ресурси баженовського комплексу поповнять спадистий видобуток нафти до 2030 р.

Ключові слова: нафтовидобуток, важкодобувні запаси, ачимовський, тюменський, доюрський і баженовський комплекси, Югра.

Introduction. In order to maintain the hydrocarbon production in Russia, there is a need for new oil production bases. These bases should be commensurate with the resources of the West Siberian oil production base, which is based on unique and large fields (Fig. 1). Such bases are usually identified in the initial stage of the exploration of oil and gas provinces. Such oil production bases have to be through created major geological exploration financed by the State. This is convincingly shown in the works of the Siberian Branch of the Russian Academy of Sciences (SB RAS), headed by academician A.E. Kontorovich [Kontorovich, 2017; Kontorovich et al., 2017].

The critical mass of proven reserves required for the starting large-scale geological exploration has not been accumulated yet either in the East Siberia or on the shelf. Data of oil resources — the total initial resources (TIR) and the sum of the undiscovered and possible ($D + C_3$ categories) resources are presented in Table 1. The re-

serve indexation by the categories is presented according to the Russian classification, 2008. This is the data of the All-Russian Research Geological Oil Insitute (ARRGOI). ARRGOI has performed an assessment of the hydrocarbon resources in 2014.

The order of figures is comparable to all territories (excluding the Far East shelf) for the undiscovered resources of D_3 category. But resources of D_3 category (in areas with unproved oil presence) are only 1.5 of 13.2 billion tons in Yugra, and only 9.1 of 12.5 billion tons in the Arctic Waters. Almost half (44 %) of the prospective resources (D_2 category) of Russia is concentrated in Yugra (these are resources of sediments and territories with proved oil). So far, in the Water Areas only the unproved resources are taken into account. There were several large deposits discovered in the East Siberia in the Soviet times. But at the moment there are no major discoveries. The pipeline system "Eastern Siberia — Pacific Ocean" (ESPO) should be largely based on reserves in West Siberia. This is the opinion of academician A.E. Kontorovich and his colleagues [Kontorovich et al., 2018]. Therefore, Yugra will remain the main resource base of oil and gas industry in Russia for many years to come. The key challenge for the Yugra oil industry is to prevent a decline in the oil production. Such problem was formulated by A.V. Shpilman in the plenary talk at the Yugra regional conference in November, 2011. Later, aspects and directions of the solution of this strategic objective were published in the periodical [Tolstolytkin, Shpilman, 2014]. The solution can be obtained by expanding the geological exploration geography. Their goal is to account some "new" oil reserves, increase the oil recovery factor (RF), at least to the Russian average level, and actively involve hard-to-recover (HTR) reserves in the development.

Materials and Methods. A retrospective analysis of the oil production has been performed in Yugra since 1964. The detailed research has been done since 2008. Subsurface Resources Management and Natural Resources Department data of the Yugra Government (Subsurface Resources Management Department of Yugra) and Yugra Autonomous Institution "V.I. Shpilman Research and Analytical Centre for the Rational Use of the Subsoil" were used.

Analysis of the oil production in Yugra. Oil production in Russia was 546.7 million tons in 2017. This is 0.1 % less than in 2016. In 2017, the Yugra's share of the all-Russian production was 43.0 %. At the end of 2016, this indicator was 43.7 % (Fig. 2).

As of January 1, 2018 the cumulative production was 11,443 million tons since the beginning of Yugra's oil fields development in 1964. The Neocom shelf sandstones are the main development object.

As of January 1, 2018 in total 483 oil and gas fields has been discovered, 257 of them are under development according to the Sub-

T a b l e 1. Total initial resources of Hydrocarbon Crude (HC) by categories $D_3 + D_2$ (billion tons)

Area	Total initial resources HC	$D_3 + D_2$
Yugra	35.5	13.2
Eastern Siberia (Krasnoyarsk Territory, Irkutsk Region, Yakutia)	14.6	11.3
Yamalo-Nenets Autonomous District	14.7	8.8
Arctic water areas	13.0	12.5
Far East water areas	2.3	1.8

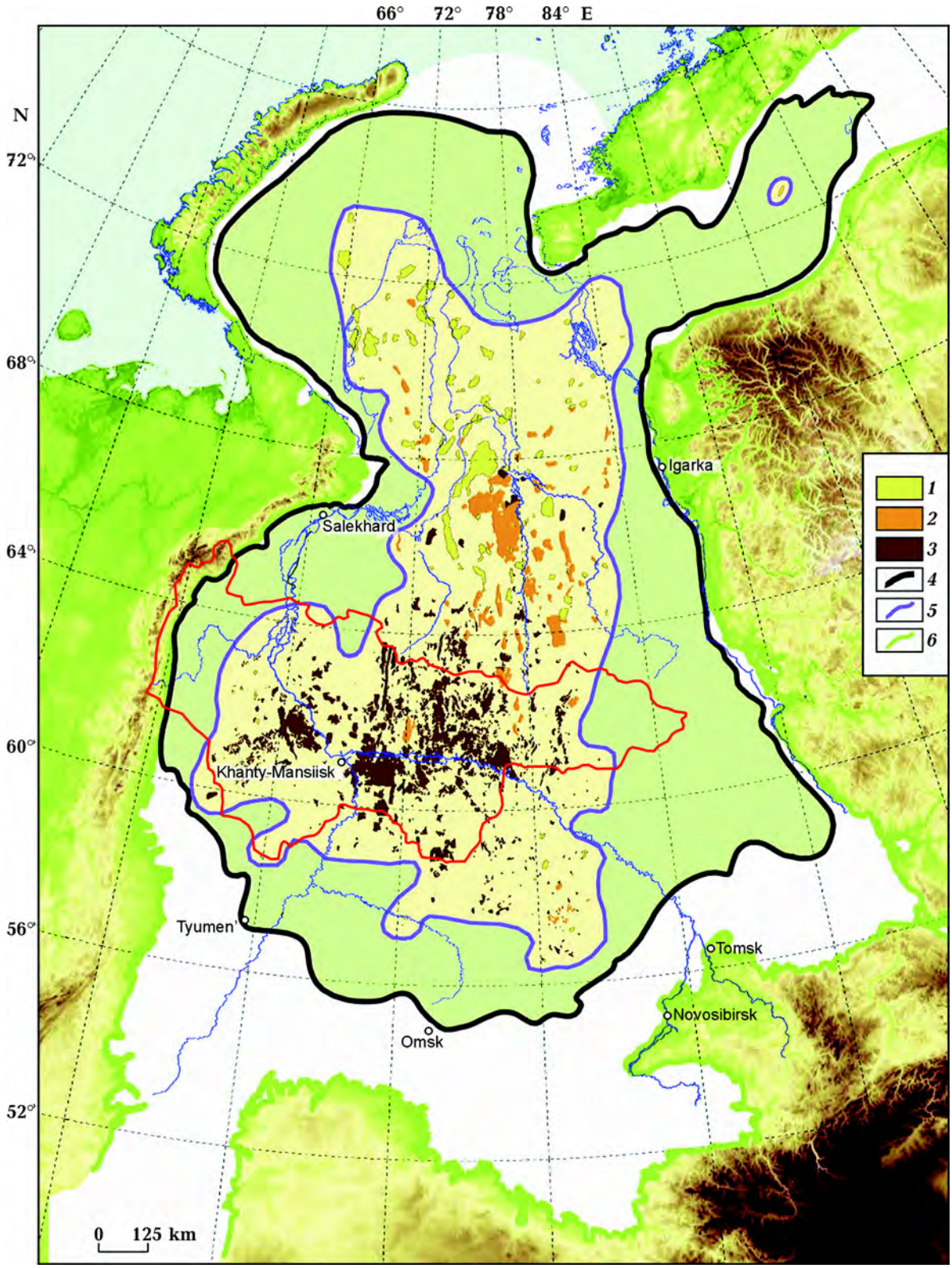

Fig. 1. Overview map of the West Siberian oil and gas province, from the message A.M. Brekhuntsov, B.V. Monastyrev, and I.I. Nesterov (Jr.) [Brekhuntsov et al., 2011]: *1—3* fields (*1* — gas and gas condensate, *2* — oil-gas and oil-gas condensate, *3* — oil); *4—6* border (*4* — West Siberian petroleum province, *5* — areas of identified oil and gas content, *6* — West Siberian geosyneclise). Red outline — the territory of the Yugra.

Fig. 2. Trend of annual oil production in the Yugra from the beginning of development work (the use of the data Department of Subsoil Use of Yugra, 2018).

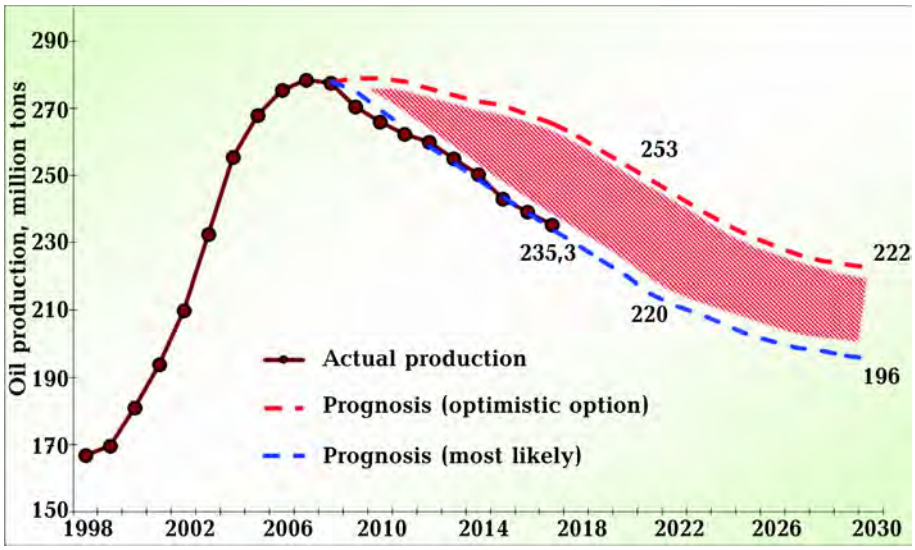

Fig. 3. Prognosis and actual annual oil production in Yugra (the data was used from the "Scientific and Analytical Center for Rational Use of the Subsoil named after V.I. Shpilman").

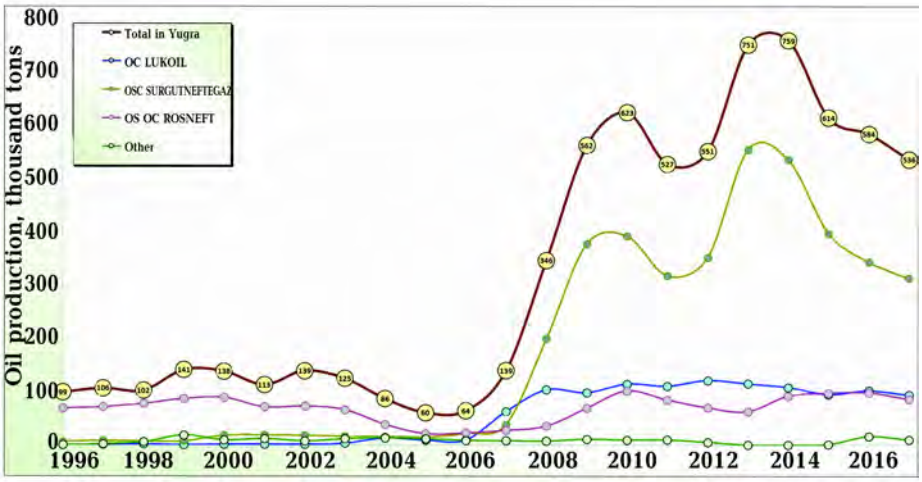

Fig. 4. Trend of annual oil production from deposits of the Bazhenov-and-Abalak play in Yugra.

surface Resources Management Department of Yugra.

There are 123 fields with recoverable reserves of more than 1.0 billion tons in the licensed areas of Yugra at various stages of exploration. Within the unlicensed areas 91 fields with recoverable reserves of more than 0.3 billion tons are registered in the State Balance of Mineral Resources.

In 2017, oil production amounted up to 235.3 million tons of oil in Yugra. This is 1.6 % loss than in 2016, or loss 3.9 million tons in absolute units. It should be noted that in 2016—2017 there was a tendency to reduce the rate decline in the oil production compared to the last reporting period. This is explained by the new technologies to enhanced oil recovery and well stimulation, also the «new» fields are actively put on production.

As of June 1, 2018 110 enterprise subsoil users are carrying out geological exploration of subsurface resources and hydrocarbon production in Yugra. Thirty six of them are part of seven vertically integrated companies and seventy four companies are independent. 98.9 % of the total oil production in Yugra are owned by major oil companies (JSC "OC "Rosneft", OJSC "Surgutneftegas", PJSC "LUKOIL", OJSC OGC "Slavneft", PJSC "Gazprom Neft", "Salym petroleum development N. In.", PJSC "RussNeft", OJSC "Tomskneft" VNK, JSC "Bashneft"). Only 1.1 % of oil is produced by 14 independent companies.

In 2017, 14 major fields accounted for 51.7 % of oil production, where each of them produced more than 3 million tons. The largest volume of oil is produced in the Priobskoye field — more than 36 million tons (JSC "OC "Rosneft" + PJSC "Gazprom Neft"), almost 19 million tons at the Samotlor field (JSC "OC "Rosneft"), 9.2 million tons at the Prirazlomnoye field (JSC "OC "Rosneft") and 8.5 million tons at the Fedorov field (OJSC "Surgutneftegaz"). In 2008, proposals were prepared for the energy strategy of Yugra up to 2020 and for the future. The experts of the "Research and Analytical Centre for the Rational Use of the Subsoil named after V. I. Shpilman" have made the forecast of the oil production decline in Yugra up to 2030 (Fig. 3). The graph indicates that the forecast (the most probable option) was fully confirmed as of 2018.

Discussion of the analysis of the state oil production. As follows from the analysis, the oil production decline in Yugra is predictable and logical process. *The main reasons for the decline in oil production are listed as follows:*

1) a significant part of the mature oil fields are characterized by a decline in oil production;
2) well drilling moves into the peripheral segments on fields, where low-productivity zones are not able to compensate for the working;
3) oil production in the largest fields which make a significant contribution to the total production in Yugra (Samotlor, Fedorov, West Salym, Tevlinsko-Russkinskoe, Vatyeganskoye, Mamontovskoye fields) is significantly reduced;
4) recently, more and more small fields have been discovered in Yugra, whereas the discovery of new major oil fields is unlikely to happen;
5) recently, the discovered and put to production targets are usually low-productive, with mostly HTR oil reserves.

If the rate of decline in the oil production in Yugra continues as projected (See Fig. 3), then the production will be 220 million tons by 2020, and production will decrease up to 196 million tons by 2030. What should be done to stabilize oil production in Yugra? There is an answer in our opinion.

Prevention of a decline in the output of the Yugra's oil industry can be obtained in the following areas:

1) to expand the geography of geological exploration to prospect "new" oil reserves;
2) to prepare and begin the industrial development of 214 fields in licensed and unlicensed areas with hydrocarbon reserves of about 1.5 billion tons in the near future;
3) to increase and lift the oil RF, at least to the Russian average level;

4) to actively involve HTR in the development .

We will focus on the last point, elaborating it in details.

Analysis of hard-to-recover oil reserves in West Siberia. The Central Commission for the Mineral Development of the Russian Federal Mineral Resources Agency (CCR Rosnedra) published the project called "Hard-to-recover reserves Classification (HTR)" in 2005. The reasons can be divided into two components: natural and man-made in accordance with the "Classification ..." which oil reserves belong for HTR. There is necessary to use geological, technological and economic criteria for determining deposits belonging to the group of HTR. Geological criteria for hard-to-recover are sufficiently formalized in the "Classification ..." by oil properties. These criteria include: viscosity (> 30 MPa·s) and bituminosity (density at 20 °C > 0.895 g/cm^3), oil paraffin content (> 6 %) and oil sulfur content (> 3.5 %). These parameters and their cut-off values take into account hydrocarbon production technology, transportation, refining, its integrated using. And these parameters are contained in the deposit characteristics of the State Mineral Resource Balance of the Russian Federation (State Balance of Russia).

According to the data of the State Balance of the Russian Federation, it is possible to reliably estimate the share and characteristics of the HTR reserves using only the above-mentioned geological criteria. According to other geological criteria, there are no formalized criteria in the data of the State Balance of Russia. The exception is permeability, however, less than half of the deposits in the State Balance is characterized by its value.

The following seven groups of deposits of HTR were identified on the basis of abnormal oil and gas properties, the unfavorable reservoir characteristics, the types of contact zones (oil-formation water, oil-gas cap), technological reasons (depletion) and geological factors in the Yugra fields.

1. Oil pools with abnormal physical and chemical properties: deposits of high viscosity (> 30 mPa · s), bituminosity (density at 20 °C > 0.895 g/cm^3), high-paraffin (> 6 %) and high-sulfur (> 3.5 %) oil.

2. Sediments of the AB_1^{1-2} reservoir commonly called "Hazel Grouse": sharp lateral and vertical lithological heterogeneity, thin interbedding of various shapes and sizes of sand and clay inclusions, RF < 0.230.

3. Rocks of the Pre-Jurassic play: belonging of deposits to a complex of Basement and rocks of Permo-Triassic; lateral and vertical heterogeneity of the reservoir properties, the dominant cavernous-pore-fractured reservoir, RF < 0.230.

4. Tyumen Formation: mosaic structure of the section with a high subsurface inhomogeneity (various sizes and shapes of the reservoir lens in the thickness of clay rocks), a lot of "sleeve-like" isolated sand bodies, a high layered and zonal filtration inhomogeneity of sediments, RF < 0.230.

5. Achimov Formation: oil pools are confined to complex traps of the wedge-shaped structure, inhomogeneous interlensing of siltstones, sandstones and argillaceous shale; the heterogeneous construction of the reservoir along the lateral and section; mainly low reservoir properties, RF < 0.230.

6. Under-gas-cap zone of deposits: oil and gas condensate pools with oil rims of small thickness (about 4 m), RF < 0,230.

7. Bazhenov Formation: belonging to the Bazhenov suite; complex geological structure of pools with sharp lateral and vertical heterogeneity of the reservoir; three types of the secondary reservoir porosity — porous-fractured, fractured and cavernous-fractured with low reservoir properties.

The cutoff of the RF is equal to 0.230 for the referring deposits of a complex geological structure to the HTR. The cutoff of the RF is determined by a group of experts of the "Research and Analytical Centre for the Rational Use of the Subsoil named after V.I. Shpilman" [Polukeev et al., 2013]. The actual differentiation by geological parameters of the deposits of Yugra HTR oil is presented in Table 2.

Discussion of analysis of hard-to-recover reserves. According to the latest official ex-

pert assessment, TIR of the Yugra deposits of the Bazhenov-and-Abalak plays are estimated as 11 billion tons. The recoverable resources are estimated as 3.1 billion tons. The recoverable reserves (C_1 + C_2 categories) are estimated as 500 million tons. At the same time just over 11 million tons of oil were produced from the Bazhenov Formation during 50 years of industrial development. This is a small part of the resources registered in the State Balance of Mineral Resources by Russian Federation.

In 2017, according to the Subsurface Resources Management Department of Yugra (Fig. 4, See p. 36) only 536 thousand tons of oil were produced from the Bazhenov Formation. This indicates that the effective exploration of HTR oil of Bazhenov deposits is possible with an active long-term State policy. The cost of implementing organizational and technological innovations in the realization of the Bazhenov Project for 8—9 years is estimated at 4.5 billion rubles by S. G. Kuzmenkov [Kuzmenkov, 2014]. Production from Bazhenov-and-Abalak Formations should be 25 million tons of oil per year by 2030. Bazhenov's resources can be involved in the development and fill the falling production trend in the West Siberia up to the thirties of this century.

The scientists of Tomsk [Lobova et al., 2016; Belozerov et al., 2018], Tyumen [Zubkov, 2017] and Moscow discuss great prospects of Bazhenov resources [Skvorcov et al., 2018]. The presence of oil in the Bazhenov Formation was discovered at the Prav-

T a b l e 2. Internals of practical referring oil deposits to the HTR reserves (the data of the Scientific and Analytical Center for Rational Subsoil, 2014)

HTR reserves characteristic	Conditions for oil recoverability factor	Oil recovery factor, fr. unit	Effective oil height, m	Factor of porosity, fr. unit	Oil-saturation factor, fr. unit	Pemeability, μm^2
Oil properties (viscosity, bituminosity, paraffin and sulfur content)	HTR	0.258	3.6	0.203	0.59	0.190
"Hazel Grouse"	All	0.319	5.2	0.218	0.441	0.215
	HTR	0.211	3.1	0.202	0.425	0.054
Pre-Jurassic play	All	0.205	10.1	0.133	0.628	0.170
	HTR	0.194	10.1	0.139	0.604	0.182
Tyumen Formation	All	0.231	3.9	0.156	0.552	0.022
	HTR	0.209	3.1	0.153	0.546	0.014
Achimov Formation	All	0.258	3.5	0.176	0.511	0.700
	HTR	0.199	3.4	0.173	0.506	0.065
Under-gas-cap zone of deposits	All	0.373	4.3	0.233	0.553	0.192
	HTR	0.221	3.5	0.237	0.509	0.169
Bazhenov Formation	HTR	0.245	3.4	0.173	0.506	0.065

dinsk field in 1967. After that, oil deposits in bituminous mudstone were discovered in other areas of the Western Siberia. Scientists of SB RAS had studied the extent of bituminous Bazhenov Formation from 0.7—1.0 million km^2 [Ryzhkova et al., 2018]. To date, the active development of HTR reserves of complex Bazhenov deposits is an important challenge for the industry. The first results were reported by scientists and experts from St. Petersburg [Prishhepa, Averjanova, 2013], Khanty-Mansiysk and Tyumen [Kuzmin et al., 2014; Shpilman et al., 2015], Tomsk and Novosibirsk [Parnachev et al., 2016; Isaev et al., 2018 a, b].

The Bazhenov Formation is not the only potentially productive object of the HTR reserves of the sedimentary mantle section in the West Siberian petroleum province. The deposits of the Achimov Formation of the Neocom play have a multi-billion tons potential. Here, recoverable reserves are estimated as more than 2 billion tons. The Tyumen Formation has a huge potential, its deposits with HTR reserves are more than 5 billion tons of oil. Reservoir of Tyumen Formation, as reported G. Lobova [Lobova, 2015] has mainly continental genesis. This leads to a deterioration of the reservoir properties compared to the Neocom shelf sandstone, which is the main production target in Yugra. The oil production of the Achimov play, characterized by A.R. Kurchikov and V.N. Borodkin [Kurchikov, Borodkin, 2011], has increased five-fold since 2000 and amounted to 21 million tons in 2017. Oil production from Tyumen Formation (considering HTR reservers) has increased to 26 million tons. Since 2000 oil production has increased by 10 times. The geologists of Tyumen Petroleum Research Center [Gorobets et al., 2010] characterized zones with a "Hazel Grouse" texture. These zones include 10 deposits with initial oil in place (IOIP) of about 0.2 billion tons. The main part of these deposits is located in the Greater Samotlor fields. As of June 1, 2018 the cumulative production of HTR oil from these productive zones was slightly over 1.5 million tons.

Pre-Jurassic play (PJuP) includes about 50 pools in the Yugra fields. These fields are located in the western part of the district. The IOIP of fields of Pre-Jurassic play are about 0.5 billion tons. The main part of the reserves is concentrated in the Triassic rocks and the Crust of weathering. The assessment accuracy of the parameters of deposits and reserves are low due to the complex lithological and mineralogical composition of rocks and reservoir type. During all the period of production of Yugra deposits from the above-mentioned deposits with HTR reserves, the total oil production is about 3% of their initial recoverable reserves and the hundredths of percent of total oil production in the district.

At the same time, the following has been noted.

One of the actual sources supporting the stability of oil production level in Yugra was active involvement of deposits if HTR reserves in the reservoir development. In 2017, the increase in oil production for only three plays (Achimov, Bazhenov-and-Abalak and Tyumen) was almost 4 million tons. This is higher or comparable with the rate of decline in the oil production in general for Yugra.

In case of PJuP, there is no increase in Yugra oil production. Nevertheless, the annual production is 2—3 million tons, and the cumulative production from PJuP for all time amounts to more than 32 million tons. As the researchers of SB RAS [Kontorovich, 2007], Moscow State University [Ablya et al., 2008; Timurziev, 2018] and Tomsk Polytechnic University [Koveshnikov et al., 2016; Lobova et al., 2018 a, b] discuss, PJuP can be one of the sources of oil production stabilization.

Conclusions. Summing up the current state of the Yugra oil and gas industry, we can stay the following.

1. In the past and the present, and well into the future Yugra is the main base of oil production in Russia for many years.

2. The involvement of deposits with HTR reserves shows that the rate of decline in Yugra oil production can be sta-

bilized and also stopped.

3. It is necessary to actively involve HTR in industrial development, including deposits of Achimov, Bazhenov, Abalak, Tyumen formations, oil of PJuP.

4. It is important the experimental scientific and production sites to be established and function, primarily for the introduction of exploration technologies for deposits of the Bazhenov-and-Abalak oil and gas plays.

The most significant HTR oil reserves are located in Russia. The recoverable reserves of HTR are 20 billion tons, whereas the resources amount to 140 billion tons. To date, the active development of HTR deposits of the Bazhenov-and-Abalak plays is an important challenge for the industry.

Acknowledgments. The authors thank Sergey A. Filatov Director of the Subsurface Resources Management and Natural Resources Department of the Yugra Government, and Alexander V. Shpilman Director of the Autonomous Institution of Yugra "Research and Analytical Centre for the Rational Use of the Subsoil named after V.I. Shpilman", for the opportunity to use geological information, and Tatyana D. Karminskaya the rector of Yugorsk State University for her attention and support of the research.

Funding Statement. The research was funded by the Yugra State University allocated under the grant for the establishment of a leading research school "Solution of technical and technological problems of development of oil and gas fields and anthropogenic transformation of the Arctic territories natural environment".

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In 2017, the Yugra's share of the all-Russian production was 43.0 %, it's 235.3 million tons in absolute units. This is 3.9 million tons less than in 2016 and 43.1 million less than in 2007. The Neocom shelf sandstones are the main development object. 44 % of the expected resources of Russia in prospective D_1 category reserves (resources of sediments and territories with proven oil) are concentrated in Yugra. The key challenge for the oil industry of Yugra is prevention of decline and the stabilization of oil production. It can be obtained by the active involving hard-to-recover reserves to the development. Criteria of hard-to-recover reserves, results and opportunities of their using for development in the conditions of Yugra fields are analyzed in the article. These are oil deposits with abnormal physical and chemical properties, under-gas-cap zone of deposits, sediments of the AB_1^{1-2} reservoir "Hazel Grouse" of type, Achimov Formation, Tyumen Formation, rocks of the Pre-Jurassic play and Bazhenov Formation. Increase in the oil production for only three plays (Achimov, Bazhenov-and-Abalak and Tyumen) was almost 4 million tons in 2017. This is comparable with the rate of decline in oil production for Yugra in general. Geological initial resources of the Bazhenov play are estimated at 11 billion tons, recoverable oil resources, at 3.1 billion tons. The primary source of the stabilization of oil production level in Yugra is involvement in the development of hard-to-recover reserves of Achimov and Tyumen plays. The production growth of the hard-to-recover reserves of the Pre-Jurassic play is possible. Now its annual production is 2—3 million tons. Resources of Bazhenov play will replenish the declining production trend by 2030.

Key words: oil production, hard-to-recover reserves, Achimov, Tyumen, Pre-Jurassic and Bazhenov plays, Yugra.

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