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METHODS TO ENHANCE OIL RECOVERY IN THE PROCESS OF COMPLEX FIELD DEVELOPMENT OF THE YAREGA OIL AND TITANIUM DEPOSIT

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Yarega oil and titanium deposit is a unique facility due to a combination of two mineral resources – oil and titanium ore – in one geologic structure.

The paper describes mining and geologic conditions of the field, as well as engineering solutions to enhance oil recovery and the efficiency of heat transfer. The author focuses on the issues of deposit opening and preparation for development, and provides recommendations regarding the exploitation procedure of the oil and titanium parts of the field, which take into account field data on the extraction rates of high viscosity oil and titanium ore from the start of deposit development. The paper contains analysis of existing technological schemes of high viscosity oil extraction and steam heating of the oil bed, as well as assessment of their feasibility. Issues of field preparation for development are reviewed from the position of accumulated practical experience, and recommendations on the feasibility of combined underground and open-pit mining are supported with evidence. The main advantages of the proposed system are explained; key technical and economic indicators are calculated.

***Key words*:** deposit, high viscosity oil, titanium ore, technology of efficient oil extraction, economic feasibility

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Introduction. Enhanced oil recovery from high viscosity oil beds requires specific engineering solutions for its extraction. The subject of research is Yarega oil and titanium deposit. Commercial oil reserves are accumulated in the oil bed 111, associated with Middle Devonian sediments of Givetian strata. The oil bed occurs at the depth of 130-220 m in Middle and Upper Devonian sandstones. Average net oil pay is 26 m. Effective average porosity is 25 %, permability – 2.0 μm^2. The oil bed is characterized by numerous tectonic faults and a dense fracture network. Oil density is 945 kg/m^3, in-situ oil viscosity ranges from 5 to 20 Pa·s, reservoir temperature – 6-8 °C, initial reservoir pressure – 1.0-1.3 MPa.

Problem statement. Basing on the analysis of existing means and methods of high viscosity oil extraction [2, 3, 6, 9] in the context of the deposit in question, it is proposed to implement a combined underground and open-pit system of field preparation and exploitation using thermoshaft technology. Taking into account mining, geologic and engineering conditions of field development, the paper justifies parameters of the proposed system and the algorithm of its implementation.

The proposed method of field development allows to reduce the time needed to attain designed rates of high viscosity hydrocarbon extraction, decreases the time of deposit exploitation, facilitates quicker preparation of the field and enhances oil recovery.

As of today, world resources of heavy oil and bitumen exceed those of light oil and amount to 750 billion tones [13, 15]. In Russian Federation the majority of heavy-oil resources are located in Volga-Ural, Timano-Pechora and West Siberian oil and gas provinces; according to different estimates, their geologic resources vary from 30 to 75 billion tones [7, 10]. The problem of heavy oil extraction is especially relevant today, due to declining increment of conventional oil reserves.

Development and implementation of efficient enhanced oil recovery (EOR) methods is a strategic task for every oil producing country. There are two approaches to solving the problem: state-financed programs of field testing and implementation of EOR technologies – USA, Canada, Norway, Indonesia, China (the program «Recurrent development of depleted oil fields») [14] – and legal regulation aimed at providing incentives for operators to take part in state programs.

In foreign countries efforts in these areas yield positive results. Cutting edge research demonstrates that in the last 15 years due to EOR methods proven recoverable reserves have increased by 1.4 times – equivalent to 65 billion tones [5], and design rate of oil recovery neared the mark of 50 % (in USA), which is 1.6 times higher than the same indicator in Russia. These values have been

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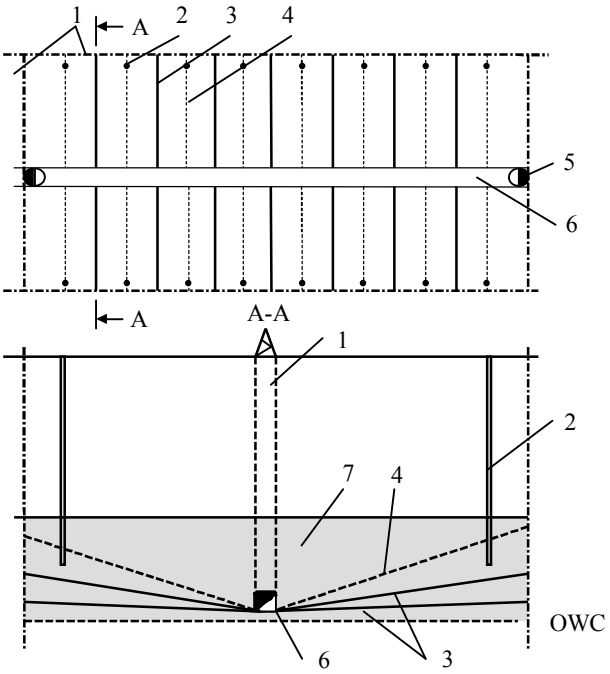


Fig.1. General model of combined underground and open-pit mining system

1 – site boundary; 2-4 – producing and steam-injecting wells; 5 – mine shaft; 6 – gallery; 7 – oil bed

attained in the context of a worsening structure of reserves and increasing share of hard-to-recover and unconventional oil.

In Russian Federation, in Komi Republic in particular, «LUKOIL» is conducting field tests at Yarega oil and titanium field. Recoverable oil reserves with a high sulphur content amount to 31 Mt, but only 5 kt are extracted annually. It is planned that in 2017 oil extraction at the Yarega field will reach 6 Mt.

Mining and geologic conditions of oil and titanium ore occurrence at the Yarega field make it possible to extract oil from the overlying Starooskolsky horizon using permanent and operational mine openings, constructed for the development of titanium ore in the underlying Afonin horizon. Current research has been performed for the license area of OAO «Yarega-Ruda», composed of four block elements with a total area of 77.5 ha, with geologic oil reserves of 2,212 kt. The aim was to provide justification for technological parameters of field development that would enhance economic efficiency of combined underground and open-pit mining technology, implying the use of mine openings for oil extraction in the 3^{bis} site [1-4].

Methodology. Complex development of the site implies development of the oil part of the field in the region of associated occurrence of oil and titanium ores by means of a combined underground and open-pit mining system, using mine openings constructed for the development of the ore part of the field (Fig. 1). In order to implement this technology and to assess its impact on the underlying ore bed, field tests have been scheduled at the pilot site with partial use of thermoshaft oil extraction technologies from the Yarega field. The main difference between combined underground and open-pit mining system and existing thermoshaft technologies lies in the fact that steam, injected into the reservoir, comes from vertical injection wells drilled from the surface, not from mine openings.

Table 1

Comparison of oil yield from test wells at 1T-2 site and OM-2 blocks, t/day

Year of exploitation	Test site 1T-2				OM-2 Blocks
	Wells 1i-3i	Wells 4i-6i	Wells 7i-9i	Average	
1st	0.01	–		0.01	0.24
2nd	0.08	–	–	0.08	0.45
3rd	0.43	0.08	–	0.40	0.46
4th	0.92	0.73	0.72	0.86	0.43
5th	1.16	1.60	0.68	1.17	0.40
6th	1.82	2.14	1.41	1.81	0.35
7th	2.07	2.36	2.72	2.33	0.30

For even distribution of the heat along the oil bed, underground steam-distributing wells are drilled from the galleries to the bottomholes of injection wells [2, 10]. Taken together, the vertical surface well and the underground steam-distributing one are comparable to a horizontal well. Steam injection into underground wells is subject to strict regulations, both in terms of underground pipe-

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line diameter and injected steam parameters. Therefore, injection pressure for underground development systems rarely exceeds 0.3-0.5 MPa, which corresponds to saturated steam temperature of 130-150 °C.

Low parameters of injected steam lead to a longer development time of the blocks, which amounts to 12-15 years. Despite high attained rates of oil recovery (average value across finished blocks – 54 %), a longer development period and higher maintenance costs of mine openings prevent the thermoshaft technology from demonstrating high economic results.

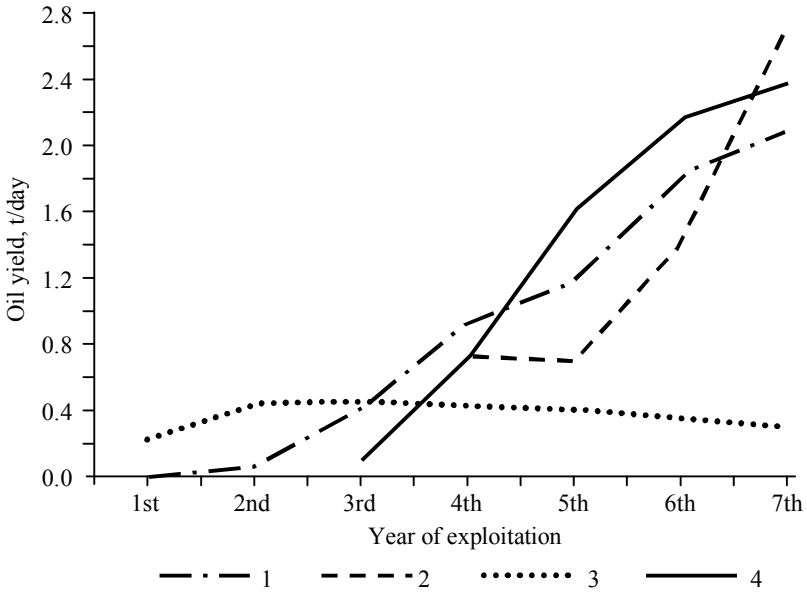


Fig.2. Average daily oil yield from test wells at 1T-2 site and OM-2 blocks
1 –wells 1i-3i; 2 – wells 4i-6i; 3 – wells 7i-9i; 4 – average yield across OM-2 blocks

A combined underground and open-pit mining system significantly eases restrictions on the rates and parameters of steam injection, as the reservoir treatment occurs through surface wells [6, 9]. In case of the Yarega deposit, the main restriction is steam temperature of 200 °C, because higher temperatures lead to in-situ oil distillation, which is inacceptable for thermoshaft development. 200 °C temperature of saturated steam corresponds to the pressure of 1.6 MPa, which is 3-4 times greater than the pressure allowed in case of underground well injection. High rates and parameters of steam injection allow to increase oil uptake and reduce the maintenance period of mine openings. It should be noted that combined underground and open-pit mining system allows to reach maximum oil recovery attainable by means of a thermoshaft technology and to develop the field with higher rates of oil uptake.

Table 2

Comparison of oil uptake indicators depending on field development time (values from the oil mine 2 over the ones from the test site 1T-2)

Year of exploitation	Rates of steam injection from reservoir volume, %	Rates of oil uptake from geologic reserves, %	Accumulated steam injection from reservoir volume, %	Oil recovery factor, %
1st	0.8/6.3	1.9/2.0	0.8/6.3	1.9/2.0
2nd	1.5/2.9	3.2/5.0	2.3/9.2	5.1/7.0
3rd	1.9/2.8	4.3/6.2	4.2/12.0	9.4/13.3
4th	2.2/2.5	4.7/9.8	6.4/14.4	14.1/23.1
5th	2.2/2.4	4.7/11.2	8.6/16.8	18.8/34.3
6th	2.0/–	4.5/–	10.6/–	23.3/–
7th	1.9/–	4.0/–	12.5/–	27.3/–
8th	1.9/–	3.7/–	14.4/–	31.0/–
9th	1.5/–	3.4/–	15.9/–	34.4/–
10th	1.4/–	3.0/–	17.3/–	37.4/–
11th	1.3/–	2.8/–	18.6/–	40.2/–
12th	1.2/–	2.4/–	19.8/–	42.6/–

The main approach of thermoshaft field development is steam-assisted gravity drainage of the reservoir, the rates of which depend on the temperature [3, 8, 11]. Field tests of the combined underground and open-pit mining system (Fig.1) have been performed for the block area 1T-2, located in the oil mine 2 (OM-2).

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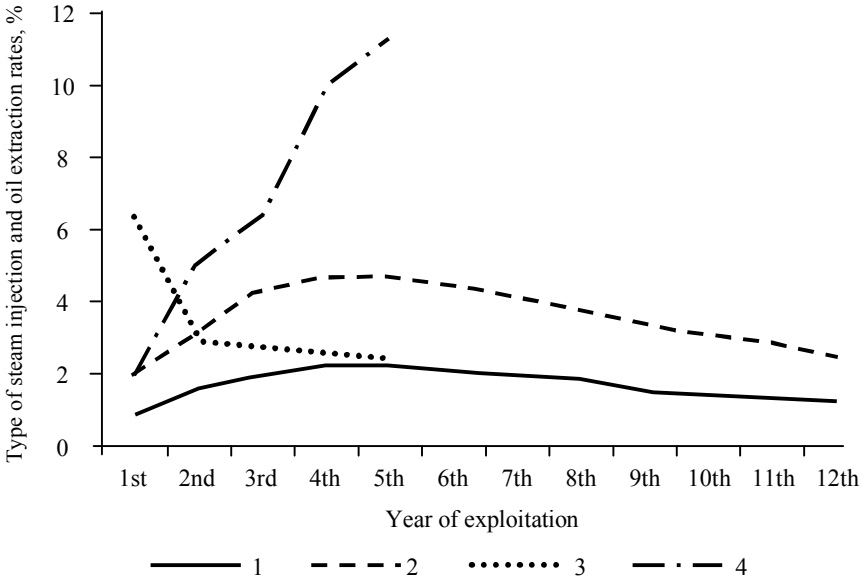


Fig.3. Development indicators

1 – steam injection rates across the blocks of oil mine 2; 2 – oil extraction rates across the blocks of oil mine 2; 3 – steam injection rate at the test site 1T-2; 4 – oil extraction rate at the test site 1T-2

The test site 1T-2 has the following parameters: area 105 thous. m^2; oil net pay 27 m, effective oil net pay 21.3 m; net-to-gross ratio 0.79; initial oil saturation 0.87; geologic reserves 468.5 kt; designed oil recovery factor 0.45; initial recoverable reserves 210.8 kt; natural oil recovery 0.025; residual recoverable reserves 199.1 kt; in-situ oil density 933 kg/m^3; initial reservoir temperature 8 °C; in-situ oil viscosity 12,000 mPa·s.

Discussion. Comparison of average daily rates of oil production from test wells at 1T-2 site to the average production rates from OM-2 blocks, being developed using different thermoshaft technologies (Table 1, Fig. 2), demonstrates that the oil yield in the former case is 5-7 times higher, excluding the first two years of exploitation, when there have been no production wells in the reservoir. Analysis of development indicators for the entire test site 1T-2, as well as for its separate parts in order of their launching, shows that annual rates of oil uptake have exceeded 9% from geological reserves and 12 % from recoverable ones. These figures surpass all other field development results for high viscosity oil and natural bitumen, existing in the world practice.

An analysis has been carried out for the dependencies of oil uptake rates from the pay formation, steam injection rates and oil recovery factor from accumulated amounts of steam injection with a regard to field exploitation time (Table 2, Fig. 3). Comparison between development indicators of the test site 1T-2 and the oil mine shows that annual oil uptake rates have exceeded 9 % from geological reserves and 20 % from recoverable ones. These figures surpass all other field development results for high viscosity oil and natural bitumen, existing in the world practice.

Conclusion. Analysis of obtained indicators allows to state that combined underground and open-pit mining system of oil extraction using thermoshaft technology is currently the most promising option for the conditions in question, and it can be recommended for the development of Starooskolsky horizon of Yarega oil and titanium deposit.

It should also be noted that a combined underground and open-pit mining system requires 2.5 times less the amount of mine openings and 4-5 times less underground well drilling per hectare of field development. Besides, such exploitation of oil deposits causes minimal damage to the environment, as the majority of technological processes of oil extraction occur below the surface.

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