ORIGINAL ARTICLE
DOI: https://doi.org/10.18599/grs.2023.3.16
Russian Original 2023. Vol. 25. Is. 3. Pp. 129–139

Efficiency of enhanced oil recovery's and oil production stimulation's methods at the oil fields of Khanty-Mansi Autonomous Okrug – Yugra

S.G. Kuzmenkov[1], M.I. Korolev[1], M.V. Novikov[2], A.N. Palyanitsina[3], O.A. Nanishvili[1], V.I. Isaev[4]*
[1]*Yugra State University, Khanty-Mansiysk, Russian Federation*
[2]*Department of Subsurface Management & Natural Resources of Khanty-Mansi Autonomous Okrug – Yugra, Khanty-Mansiysk, Russian Federation*
[3]*Saint Petersburg Mining University, St.Petersburg, Russian Federation*
[4]*National Research Tomsk Polytechnic University, Tomsk, Russian Federation*

Abstract. Stabilization of oil production at the level of 215–220 million tons/year, as well as its subsequent growth, is a priority task for the enterprises of the fuel and energy complex of Khanty-Mansi Autonomous Okrug – Yugra (KhMAO – Yugra). It is impossible to achieve this without the active implementation of the most effective modern technologies for enhanced oil recovery. This article aims to analyze the methods of enhanced oil recovery and and oil production stimulation methods (EOR and PS) used at the KhMAO – Yugra fields on an industrial scale, their features and their contribution to additional oil production from 2001 to 2021.

The article describes such technologies as sidetracking (STB), physical and chemical methods (FCM), hydraulic fracturing (HF), bottom-hole treatment (BHT), hydrodynamic methods (HDM), horizontal well drilling (SHD), as well as other geological and technical measures (GTM) aimed at optimizing well operation (other methods (OM)). The study showed that FCM, BHT and other well interventions became the most used. The share of additional oil produced through the use of EOR and PS has doubled since 2013: 8% in 2013, 16.2% in 2021. Hydraulic fracturing, deep drilling and sidetracking showed the highest efficiency. All this led to the stabilization of the annual oil production in KhMAO – Yugra and even to its growth in 2021.

The use of enhanced oil recovery methods on a non-alternative basis in developed fields is especially important, because the share of hard-to-recover reserves is high and reaches 80% for some companies in the Khanty-Mansi Autonomous Okrug – Yugra. For such fields, it is necessary to strengthen scientific research in the field of substantiation of optimal conditions for well construction, as well as the operation of development systems.

Keywords: hard-to-recover reserves, oil recovery factor, methods for enhanced oil recovery methods, oil production stimulation methods, retrospective analysis, Khanty-Mansi Autonomous Okrug – Yugra

Recommended citation: Kuzmenkov S.G., Korolev M.I., Novikov M.V., Palyanitsina A.N. , Nanishvili O.A., Isaev V.I. (2023). Efficiency of enhanced oil recovery's and oil production stimulation's methods at the oil fields of Khanty-Mansi Autonomous Okrug – Yugra. *Georesursy = Georesources,* 25(3), pp. 129–139. https://doi.org/10.18599/grs.2023.3.16

Introduction

The high level of oil production in the Khanty-Mansi Autonomous Okrug – Ugra (KhMAO – Yugra) for many years was facilitated by the development of large fields and highly productive deposits, most of which have entered a late stage of development. The current stage of field development in KhMAO – Yugra is characterized by a decrease in production at most oil production facilities, an increase in the current depletion (more than 61%) and water cut (over 85%) of the developed fields, as well as an increase to 65–70% in the share of hard-to-recover (HTR) reserves, involved in development (Vodyasov, 2022; Polukeev et al., 2013).

The main task of the enterprises of the fuel and energy complex (FEC) of KhMAO – Yugra, along with the commissioning of fields with insignificant reserves and remote from the existing infrastructure, is the search and implementation on a production scale of new and improvement of used technologies for involving in the development of fields with HTR reserves. This requires a large amount of research, unique equipment, the use of modern technologies and methods for enhancing

*Corresponding author: Stanislav G. Kuzmenkov
e-mail: ksg.1948@ya.ru

oil recovery and intensifying oil production, aimed at improving the use of the production well stock.

Today, for the Russian Federation (RF) in general and KhMAO – Yugra in particular, the priority measures to continue stabilizing the level of oil production should be considered:

– increasing the number of auctions and competitions for the granting of subsoil use rights in the territory of KhMAO – Yugra;

– increasing the number of areas transferred for geological study in order to search for and evaluate mineral deposits at the expense of subsoil users;

– putting into industrial circulation small deposits that are unprofitable for development today and remote from the existing infrastructure (Kuzmenkov et al., 2019);

– introduction into industrial development of HTR reserves, primarily open oil deposits of the Abalak-Bazhenov oil and gas complex (Polukeev et al., 2013);

– introduction on an industrial scale of methods for enhancement oil recovery and intensifying oil production, the latter being the most effective in the conditions of Western Siberia.

Materials and methods

This work used thematic, analytical and reporting materials from fuel and energy complex enterprises, the Department of Subsurface Management & Natural Resources of of KhMAO – Yugra and the Shpilman Research and Analytical Center for Rational Subsoil Use. The analysis of these materials made it possible to assess the current state of hydrocarbon production in KhMAO – Yugra. To assess the effectiveness of measures to enhance oil recovery for the period from 2001 to 2021, a retrospective analysis of the methods used for EOR and PS was carried out, such as: physical and chemical methods (FCM) – 41,871, bottomhole treatment zones (BHT) – 37367, other methods (OM) – 34,174, hydraulic fracturing (HF) – 22124, hydrodynamic methods (HDM) – 18,834, sidetracking – 11,834, horizontal well drilling (SHD) – 11,795 operations, as well as volumes of additionally produced oil.

Results

The state of hydrocarbon production in the KhMAO – Yugra

Since the beginning of the development of oil fields in the KhMAO – Yugra (1964), accumulated oil production as of January 1, 2023 amounted to 12,565.4 million tons.

In 2022, 223,076.5 thousand tons of oil were produced in the territory of the KhMAO – Yugra (Fig. 1), which is 3.4% more than production in 2021, or 7.3 million tons.

The volume of oil production in the Russian Federation as a whole in 2022 amounted to 535 million tons, which is 2.2% more than production in 2021. The share of KhMAO – Yugra accounts for 41.7% of all-Russian production, in 2021 this figure was 41.2%.

On the territory of KhMAO – Yugra, as of January 1, 2023, there are 484 hydrocarbon fields on the state balance sheet, including: 421 oil, 23 oil and gas condensate, 18 gas, 5 gas condensate, 17 gas and oil.

There are just over 290 fields in industrial development, with 52% of annual production coming from 15 fields (Fig. 2), most of which were put into industrial development in the 20th century.

Analysis of the dynamics of oil production in KhMAO – Yugra for the period 2000–2021 (Fig. 1) showed that oil production has been declining since 2008 (Korkunov et al., 2013) and only in 2018, for the first time in the last 10 years, an increase in production was observed, exceeding the production of the previous year (Kuzmenkov et al., 2018).

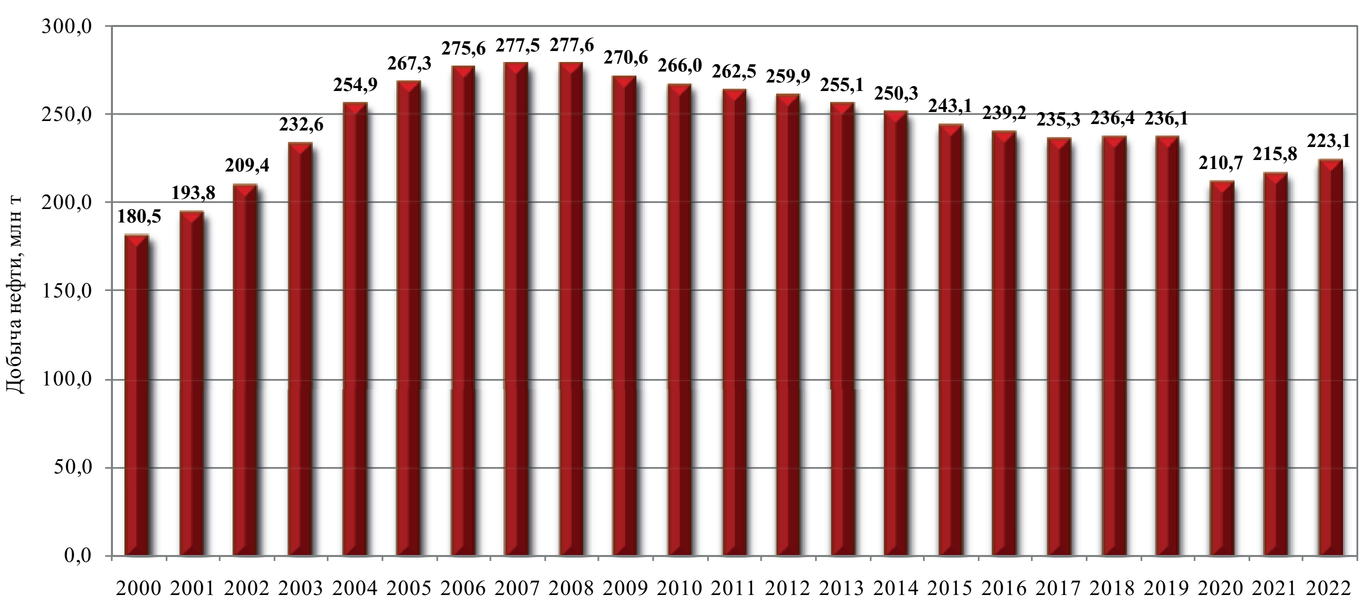

Fig. 1. Dynamics of oil production in Khanty-Mansi Autonomous Okrug – Yugra in the 21st century

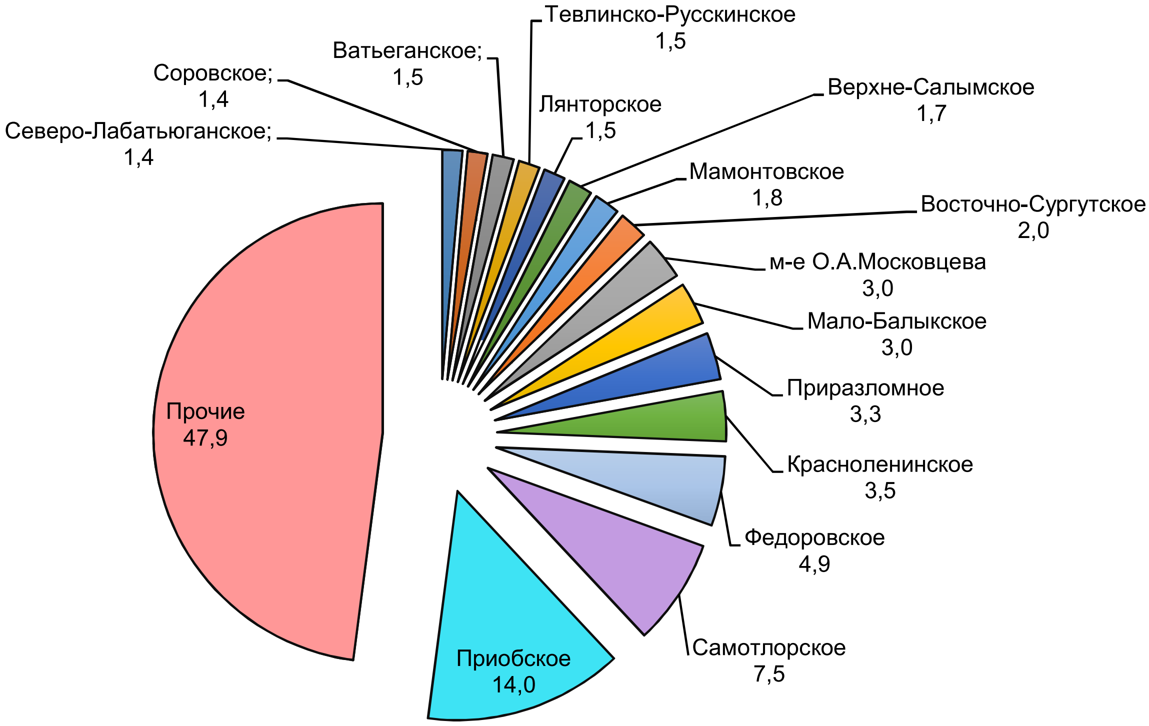

Fig. 2. Share of oil production (%) for large fields of KhMAO – Yugra

The general decline in oil production in KhMAO – Yugra is natural and predictable. In recent years, the structure of proven reserves has been deteriorating. A high percentage of developed fields are at a late stage, which is characterized by a decrease in production volume and an increase in water cut. The likelihood of discovering new large fields in existing oil and gas complexes is low. The newly discovered fields and deposits are smaller and characterized by low flow rates. Most development drilling is less efficient because it is carried out in the marginal zones of deposits. Accordingly, new reserves involved cannot compensate for the reduction in production of already developed highly productive zones (Tolstolytkin et al., 2019).

In KhMAO – Yugra in recent years (2020–2022), the increase in production levels was ensured by a number of measures (Kuzmenkov et al., 2020; Vodyasov, 2022), among which it should be noted:

– stimulation of investments by subsoil users;

– maintaining production drilling volumes at a high level (15–17 million m);

– commissioning of new (up to 3–4 thousand/year) production wells and 2–3 new fields;

– development of “road maps” for the accelerated commissioning of new fields;

– timely preparation and transfer to users of new promising subsoil areas;

– reduction of the stock of inactive wells;

– increasing the productivity of production wells due to the introduction of modern technologies of EOR and PS into production mode.

Stabilization of production in KhMAO – Yugra due to EOR and PS

A retrospective analysis of EOR and PS, applied from 2001 to 2021 inclusive, showed (Fig. 3) that over a twenty-year period, out of a produced volume of oil of 5170 million tons, additional production due to their use amounted to only 619.7 million tons, or 12 %. Maximum additional production was observed in the period 2001–2004, mainly due to the significant coverage (up to 50% or more) of EOR and PS of the operating well stock. Since 2013, there has been a slight but constant increase in additional production: from 8.6% in 2013 to 16.2% in 2021, i.e. almost twice.

Figures 4 and 5 show the number of geological and technical measures (GTM) carried out on a production scale by year. It can be seen from the figures that over 20 years, the most used BHT (115,965 well operations) and FCM (115,319 well operations), followed by OM (85,959 well operations), hydraulic fracturing (69,244 well operations) and HDM (69,244 well-operations), then sidetracking (26,511 well-operations) and SHD (17,501 well-operations).

In recent years, oil producing companies in the KhMAO – Yugra have sharply increased oil production by increasing the number of geological and technical measures that have proven their production efficiency and introducing new technologies aimed at increasing the oil recovery factor, including when developing facilities with terrestrial oil reserves (Fig. 3).

The year 2021 is indicative, when the mining enterprises of the KhMAO – Yugra, through the use of modern technologies aimed at both intensifying the selection (hydraulic fracturing, BHT) and improving the production of reserves (sidetracking, SHD, FCM, HDM), additionally received 34.9 million tons, or 16.2% of the total oil production in the KhMAO – Yugra, which is 575.1 million tons (+1.7%) more than in 2020 (34.4 million tons). A total of 27,173 well operations were carried out with EOR and PS, which is 1 well-operation less than in 2020 (27,174 wells-operations).

Specialized oil companies carried out 26,994 well operations, which is 99.34% of all well operations carried out in the district during the reporting period, additional oil production from them amounted to 34,197,217 tons, the average specific efficiency was 1267 t per one well-operation.

Independent enterprises carried out 179 well operations. using EOR and PS, additional oil production from them amounted to 749,014 tons, the average specific efficiency was 4184 tons per 1 operational well.

Note that in 2020–2021 FEC enterprises, taking into account the effectiveness of the applied GTM, increased the carrying out of geological surveys, well treatment, and sidetracking, reducing the hydraulic fracturing and the use of physico-chemical methods (Figs. 4 and 5).

Table 1 provides summary information on the EOR and PS measures carried out in 2021 on the territory of KhMAO – Yugra, and the effect obtained from them. The largest number of well operations were performed to treat the bottom-hole zone, but the maximum volume of additional oil and, therefore, specific efficiency was obtained with SHD.

Below is a retrospective analysis of the technological effectiveness of geological and technical measures carried out on the territory of KhMAO – Yugra in the period from 2001 to 2021.

Analysis of technological efficiency of horizontal wells

Involvement in the development of HTR oil resources using horizontal wells (HW) and horizontally branched wells (HBW) is currently, and as practice has shown, one of the priority areas. The use of wells of these types makes it possible to increase the length of drainage channels and improve wells productivity (Brekhuntsov et al., 2011).

The experience of drilling horizontal wells and HBW has shown that, despite the high cost of horizontal wells compared to vertical wells, the systematic application of the method ultimately makes it possible to significantly, and primarily due to the optimization and enlargement (by several times) of the operating well stock, increase the profitability of capital investments. Also significant are the increase in the service life of wells without the use of waterflooding, the reduction of drawdown on the reservoir and, most importantly, the introduction of off-balance (including pillars) and HTR oil reserves into active development. At the same time, production loads on the environment are sharply reduced, which allows the exploitation of fields (deposits) located in environmental zones. Note that in 2001–2003 horizontal wells were drilled in pilot mode (162 wells in 2003), in 2010 already 365 wells at 51 fields were put into operation, then in 2021 more than 2620 wells were drilled (Fig. 6). The maximum specific efficiency was achieved in 2005 (13,600 tons/operation-well), starting from 2010 (9000 tons/operation-well), it gradually decreases to 5890 t/operation-well in 2021, i.e. over 20 years, the efficiency of oil production per operating well due to hydrocarbons, it decreased by half, but additional production from 884 thousand tons in 2001 increased to 15,431,000 tons in 2021, or 17.5 times.

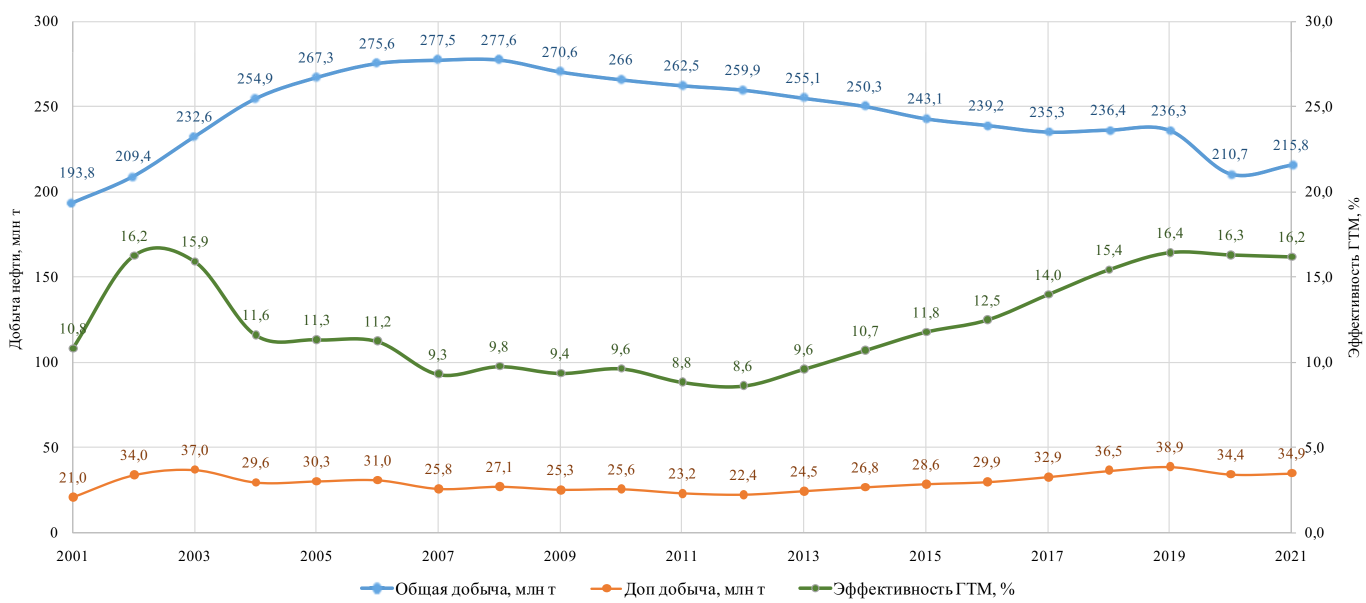

Fig. 3. Additional oil production due to geological and technological measures carried out in the period from 2001 to 2021

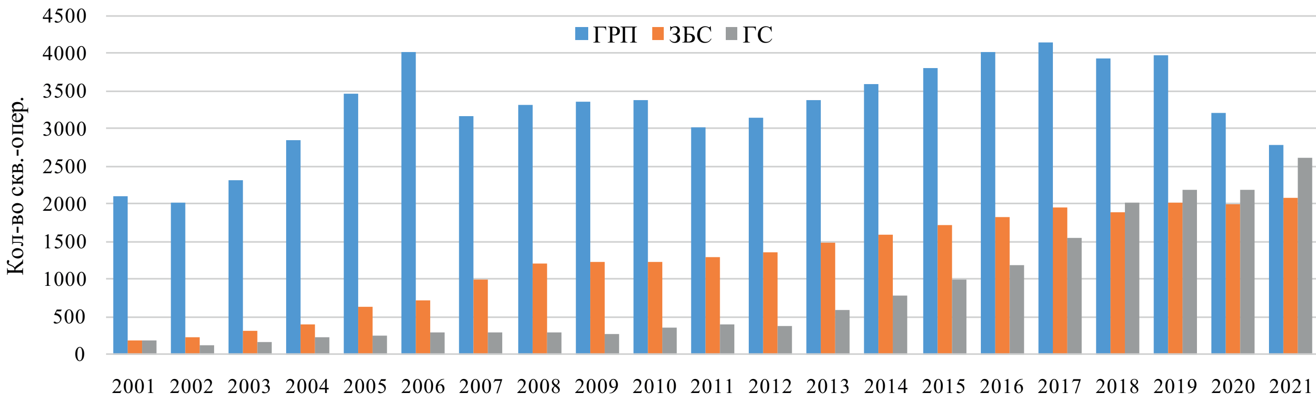

Fig. 4. Dynamics of changes in hydraulic fracturing, sidetracking and SHD used on a production scale in the period from 2001 to 2021

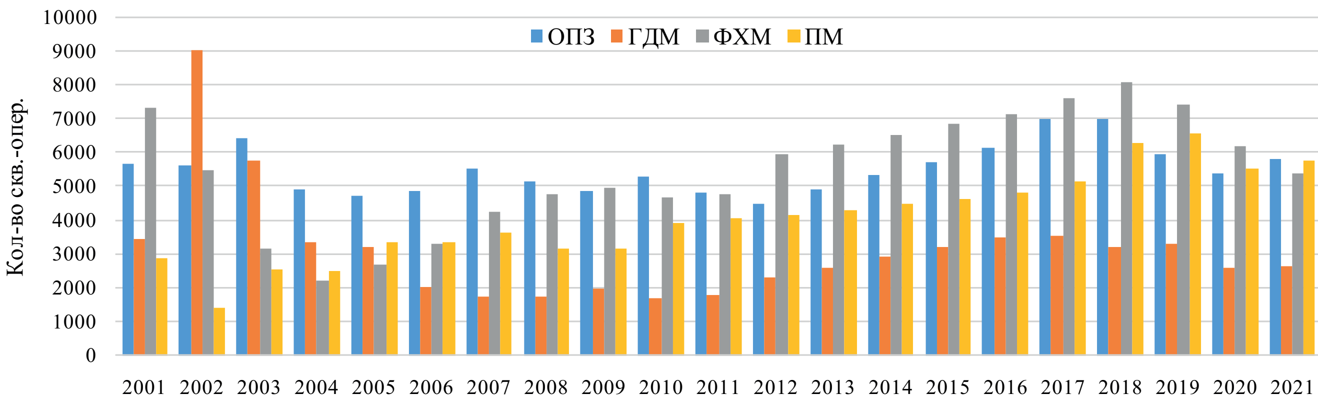

Fig. 5. Dynamics of changes in BHT, HDM, FCM, and workover used on a production scale in the period from 2001 to 2021

Well operations	Total amount (%)	Additional oil production, thous. t	Specific efficiency per one well-operation, thous. t
BHT	**5842 (21.50%)**	3222.7	0.55
OM	5800 (21.34%)	4100.3	0.71
HF	5380 (19.80%)	3090.1	0.57
HDM	2796 (10.29%)	3180.3	1.14
HDM	2640 (9.72%)	817.9	0.31
SHD	2622 (9.65%)	**15430.8**	**5.89**
STB	2093 (7.70%)	5103.9	2.44

Table 1. The number of well-operations carried out in 2021 on the territory of the Khanty-Mansi Autonomous Okrug – Yugra, and the effect of them

Analysis of the technological efficiency of using hydraulic fracturing technologies

Until 2000, all hydraulic fracturing technologies, with rare exceptions, were limited to the injection of small volumes of proppant (from 10 to 16 tons) using predominantly fine-grained fractions. Since 2002, when it became possible to model hydraulic fracturing in relation to various types of reservoirs, including HTR reserves (Orenburkin et al., 2019), there has been a qualitative leap in the development of HF as a technology for enhancing oil recovery in general. The economic feasibility of carrying out multi-volume HF (from 100 tons or more) using various fractions (including large differences) of proppant was justified. The widespread introduction of systemic HF and its varieties is beginning, including HF simultaneously in the injection well and the surrounding wells of the production stock, which has increased the efficiency of single HF on deposits that are insignificant in terms of area and reserves.

In the work (Astafiev, Samoilov, 2015) it was proven that when creating a project for the development of HTR reserves, it is necessary to take into account both geological and technological indicators. Geological factors include the thickness of the formation, its permeability, as well as its horizontal and vertical anisotropy, and the thickness of the clay bridges. Technological risks include unplanned risks of premature

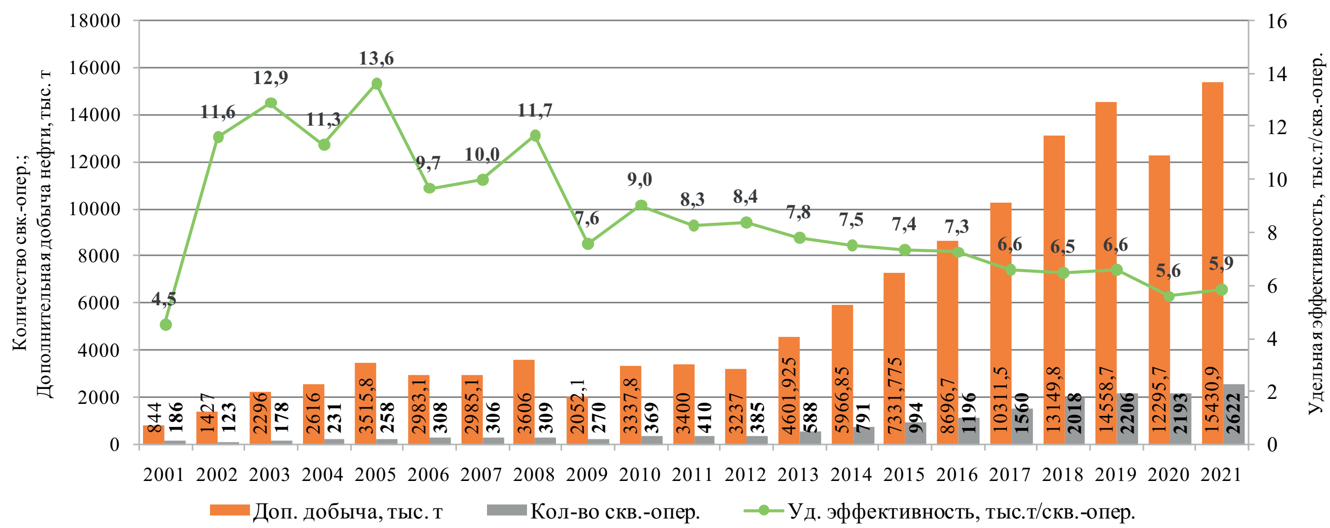

Fig. 6. Dynamics of well operations and additional oil production from the use of horizontal wells in the period 2001–2021

hydraulic fracturing shutdown, as well as the expected geometry of fractures. Figure 7 presents data on the number of HF carried out over a twenty-year period. Maximum efficiency (4.5 thousand tons/well-operation) of hydraulic fracturing was achieved in 2003 mainly due to significant (up to 45%) technology coverage of new wells put into development. During the analyzed period, due to the conducted 69,244 well-operations, the hydraulic fracturing produced 132,697.1 million tons of additional oil.

Analysis of the technological efficiency of sidetracking

Analysis of sidetrack (ST) drilling (Fig. 8) showed that in the period from 2001 to 2005, a total of 1735 ST were drilled, resulting in 9,721,300 tons of additional oil, specific efficiency during this period varied from 3300 to 6700 t/well-operation in 2004, the average was 5300 t/well-operation.

The dynamics of ST drilling during the analyzed period increased by few times, from 191 in 2001 to 2093 wells-operation in 2021, and only in the last two years (2020–2021) additional production due to drilling of ST amounted to 10.4 million tons, the average specific efficiency was 2.5 thousand tons/well-operation.

It should be noted that today the most promising and effective EOR and PS, among those inaccessible to other methods for geological and technical reasons, is the technology of sidetracking, which is increasingly being introduced on a production scale. Meanwhile, sidetracking, including drilling of multi-lateral and branched-horizontal wells, are the main element in other highly efficient technologies for the development of HTR reserves and/or high-water-cut and low-yield wells implemented during oil production (hydraulic fracturing of various modifications, HW, FCM, etc.) and/or high-water-cut and low-yield wells, the number of which (Nanishvili et al., 2019) currently amounts to more than 17,000, and the stock of idle wells exceeds 6500.

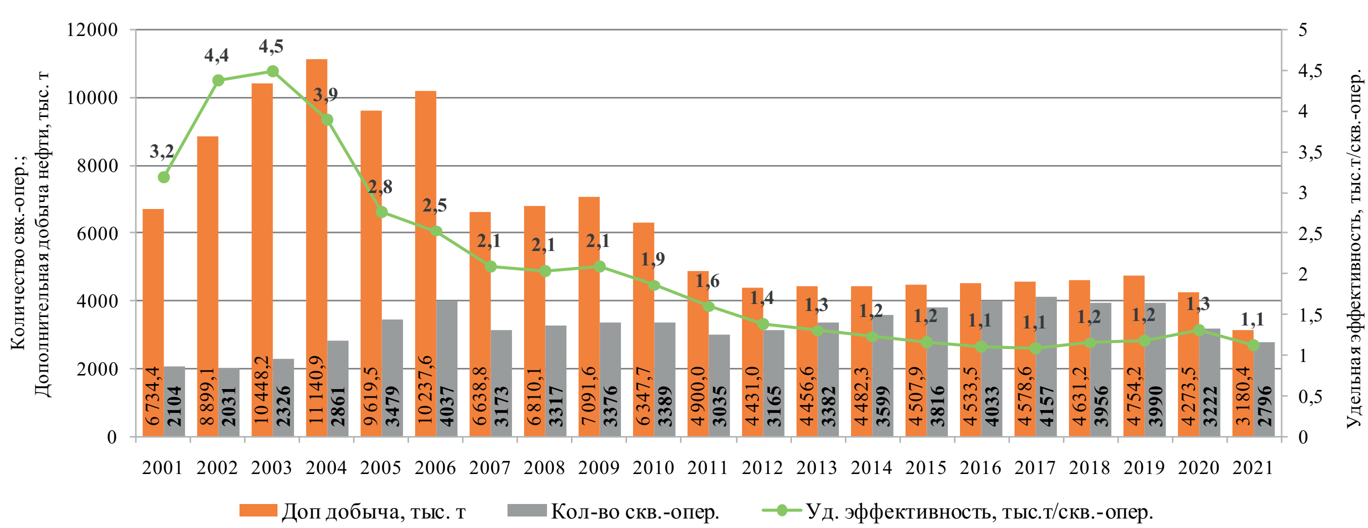

Fig. 7. Dynamics of well operations and additional oil production from the use of hydraulic fracturing in the period 2001–2021

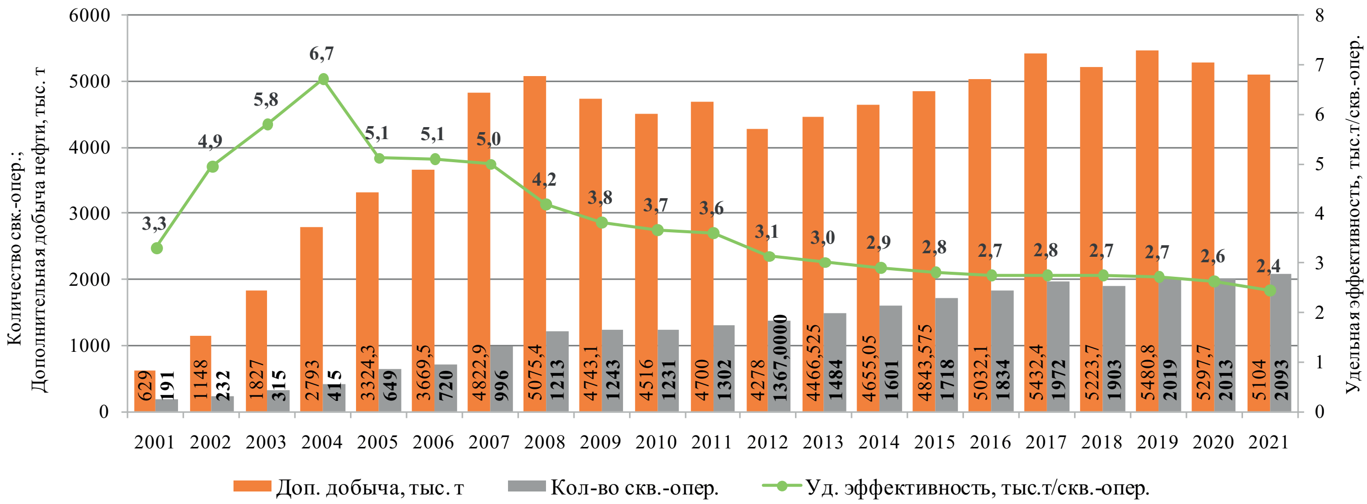

Fig. 8. Dynamics of well operations and additional oil production from the use of sidetracking in the period 2001–2021

Analysis of the technological efficiency of BHT operations

Treatment of the bottomhole formation zone is used both in production and injection wells to restore well productivity, improve filtration properties (increase permeability) of the bottomhole formation zone (BHZ) and clean pores and cracks from plugging material. This technology is based on the ability of various acid compositions to dissolve the rocks of productive formations, as well as various slurries, suspensions, and weighting agents that contaminate the reservoir zone. Figure 9 shows the dynamics of the BHT operations for the 2001–2021 period.

The analysis of the BHT showed that in 2001–2010 to increase oil recovery of reservoirs, such BHZ treatment technologies were used, as solvents, hydrogels, injection of surfactants, hydrochloric acid (HCl) and clay acid treatment (CAT) solutions into the reservoir. Then since 2010, along with the above, they began to be used acid compositions, including high viscosity treatment systems (HVTS), emulsified acid treatment (EAT), thermal foam acid (TFA) and other complex water-gas-insulating treatment compositions.

In test mode, but in fairly large volumes, complex physical and chemical measures were carried out, such as: HCl treatment and/or mud-acid treatment (MAT) with subsequent pulse-wave stimulation (PWS); deep drawdown method (DDM); variable drawdown method (VDM) + swabbing; thermogas chemical impact (TGCI); hydro-impulse stimulation (HIS); plasma pulse stimulation (PPS); use of a powder generator of pressure (PGP).

Despite the insignificant, but quite stable and inexpensive in terms of the cost of work, the specific efficiency of the well treatment area (Fig. 10), the share of such well operations varied from 25.8% in 2010 to 21.49% in 2021 of the total volume of activities.

Analysis of the technological efficiency of FCM treatment

Today, HTR resources are characterized, among other things, by high variability of reservoir porosity

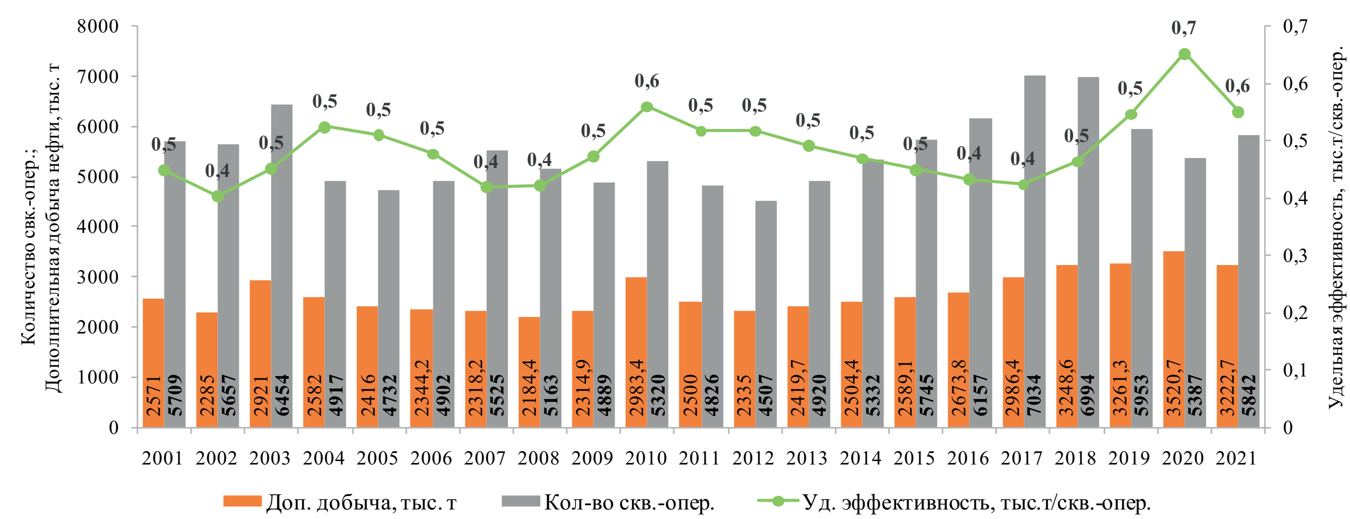

Fig. 9. Dynamics of well-operations and additional oil production from the use of BHT in the period of 2001–2021

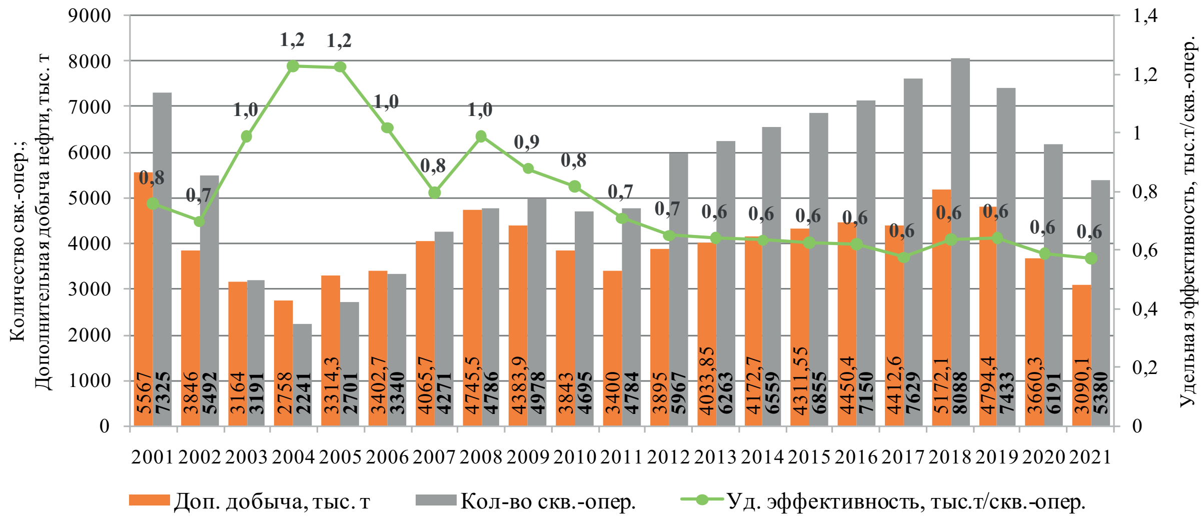

Fig. 10. Dynamics of well-operations and additional oil production from the use of FCM in the period of 2001–2021

and permeability and, accordingly, high filtration heterogeneity. To involve such reserves in development, FCM for enhanced oil recovery are actively used. Among the FCM used for additional oil production from highly water-cut, depleted formations with dispersed and irregular oil saturation, flow diverter and oil-washing technologies can be distinguished. The main component when applying the methods is water mixed with chemical reagents. In total, more than 30 flow diverting technologies are used in the fields of the KhMAO – Yugra, but domestic emulsion-suspension fluids (ESF), gel forming fluids (GOS), thermotropic gelling fluids (ThermoGOS), thermogelling compositions (RV-ZP-1) compositions, as well as their modifications (GOS-1, GOS-1AS, GOS (OPR AN125) (Dolgov, 2021).

Since 2015, the water-soluble sediment-forming composition SOT-12 has been tested in the fields of the KhMAO – Yugra. The composition works on both technical and mineralized water and is a mixture of dry components (Astafiev, Samoilov, 2015). The blocking principle of operation of the composition is associated with the temperature conditions of the formation and is limited by its thermal energy (from 500 °C). When the temperature rises, 60% of the injected SOT-12 composition is transformed into a crystalline precipitate, which retains its properties at temperatures up to 130 °C. The optimal area of application of this composition is the identified oil losses due to high water cut in the area of injection wells with an injectivity of up to 70 m^3/day, that is, in conditions where many compositions show poor efficiency.

Among oil-washing compositions, hydrocarbon solutions of esters of higher saturated acids with the addition of a complex heat stabilizer and nonionic surfactants (aldinol + surfactant), as well as an aqueous solution of hydrochloric acid and an acid modifier (KSPEO + surfactant), which have shown the highest specific efficiency (Fig. 10), are widely used.

Analysis of the technological efficiency of hydrodynamic methods (HDM) for EOR

Among the hydrodynamic methods (Fig. 11) aimed at involving undrained reserves in the development, leveling the inflow profile in layers and isolating highly water-cut layers, in the KhMAO – Yugra, mainly integrated technologies are used, which make it possible to extract residual oil at the final stages of field development by reducing the current water cut extracted products. At the present stage, this is primarily non-stationary (cyclic), step-thermal and barrier flooding, forced fluid withdrawal (FFW).

FFW has recently become increasingly used in formations with a water cut of more than 75% and a high degree of structural heterogeneity both vertically and along the length of the formations. With this method, areas of the formation that are not covered by waterflooding are involved in development. Oil recovery increases due to rise of pressure gradient and filtration rate of the fluid flow, and film oil became separated from the surface of the reservoir rock.

To reduce the rate of water cut increase in carbonate and terrigenous reservoirs and to involve undeveloped oil reserves in the conditions of hydrodynamically connected interlayers into development, an effective method for increasing oil recovery is non-stationary flooding (NSF). This method allows you to change the direction of filtration flows (Isaev et al., 2019).

The maximum effect from NSF can be obtained if, when shutting down wells, a redistribution of the reservoir pressure field occurs, then the following is possible:

– vertical flows of oil between connected, differently permeable oil-saturated layers;

– changes in the direction of filtration flows over the area of formation, when oil from lenses and stagnant zones is involved in the process of displacement into development.

The integrated application of non-stationary waterflooding together with the individual application of flow-diverting technologies to specific injection wells leads to the greatest effect in reducing the water cut of products, as evidenced by the redistribution of pressure gradients and the formation of interlayer flows during the implementation of NSF. In addition, there is an effect from the targeted use of flow-diverting compositions. To achieve optimal results from the use of such compositions in injection wells, it is recommended to perform selective plugging of highly permeable interlayers with increased water content. After treatment, it is necessary to monitor the formation pressure so as not to cause the formation of man-made cracks (Zakharova, Zagidullin, 2015).

Figure 11 shows that in the period from 2001 to 2007, the number of hydrodynamic methods used was maximum, and in the subsequent period to the present day, the number of well operations remains at the level of 2–3 thousand with low specific efficiency (0.4 thousand tons). Let us note that this additional oil was obtained from those objects (deposits, interlayers, lenses, pillars), which would be simply impossible to extract using other GTM. Thus, this method must continue to be used in order to additionally extract "residual" oil from objects diluted as a result of improper development.

Analysis of the technological efficiency of other workover methods

Other workover methods are used mainly when carrying out repair and isolation work, they include additional shots, reshoots, returns to overlying formations, commingling formations, isolation work, production intensification (reducing drawdown on the formation), optimization and transfer to mechanical production, work with the well stock.

From Fig. 12 it follows that during the analyzed period, additional production due to workover increased by 40% mainly due to an almost doubling of the well operations performed: from 1444 in 2002 to 5800 in 2021. This indicates that fuel and energy companies are actively are implementing these methods in order to reduce the idle stock of wells, increase operating time and involve idle formations in production.

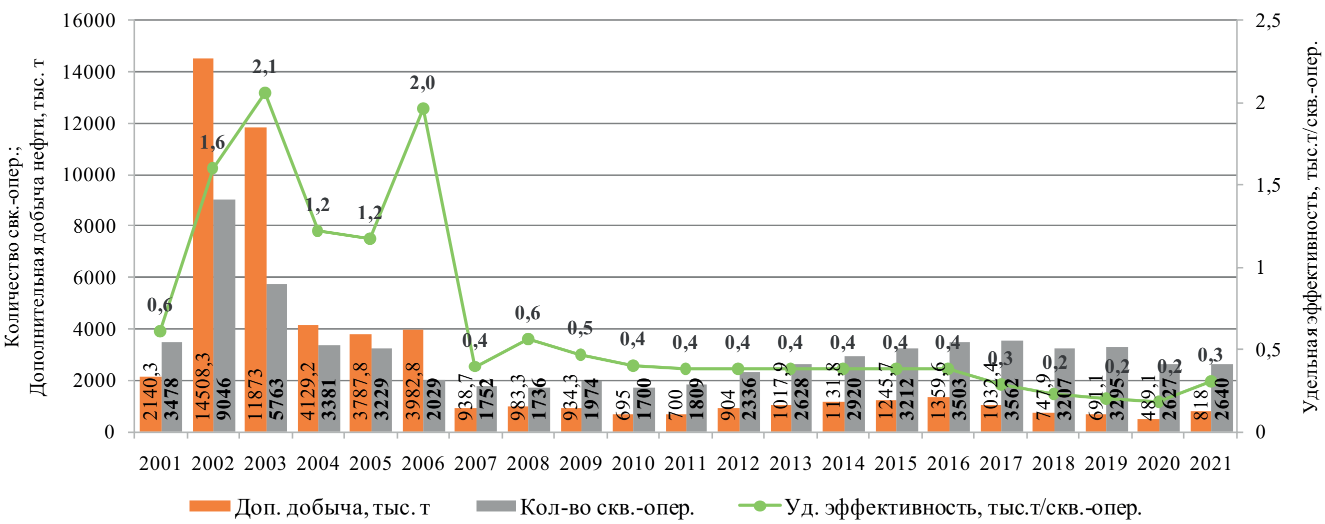

Fig. 11. Dynamics of well-operations and additional oil production from the use of HDM in the period of 2001–2021

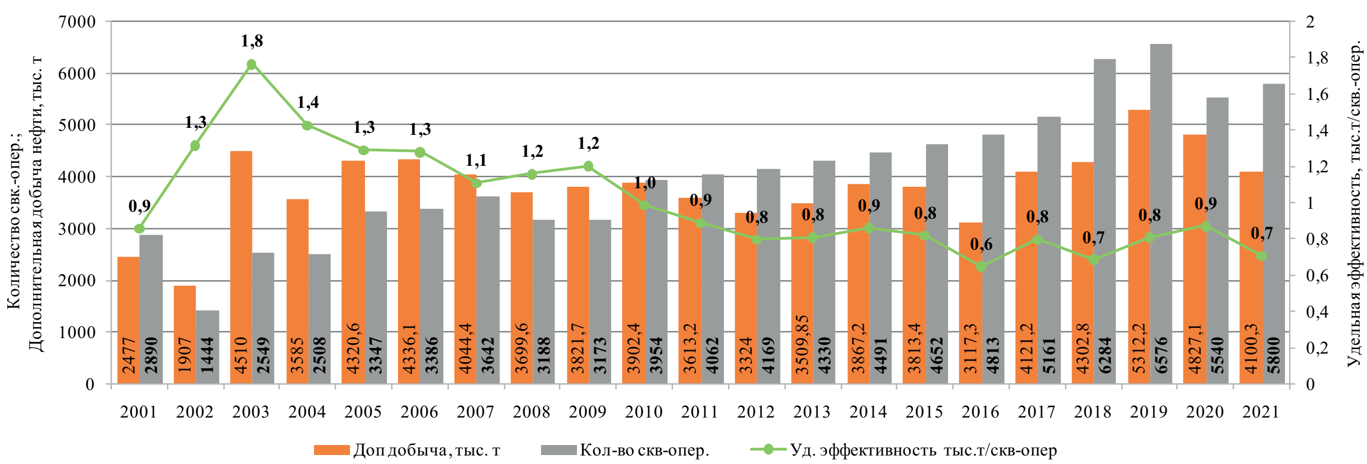

Fig. 12. Dynamics of well-operations and additional oil production from the use of workover in the period of 2001–2021

Conclusion

In the Khanty-Mansi Autonomous Okrug – Yugra, despite the sanctions imposed by Western countries, annual oil production stabilized at the level of 217–220 million tons, including due to EOR and PS measures.

The most widely used EOR and PS are FCM, BHT and workover; the most effective methods that provide maximum additional production are hydraulic fracturing, sidetracking and horizontal wells drilling.

The volume of additional oil production due to the introduction of EOR and PS in production mode in the period from 2001 to 2021 amounted to 620 million tons, or 12% of the total production of 5170 million tons.

Maximum additional production due to EOR and PS was observed in the period 2001–2004 mainly due to the coverage of the operating well stock by these methods (up to 50% or more). Since 2013, the volume of additional production has increased slightly but constantly: from 8.6% in 2013 to 16.2% in 2021, i.e. almost twice.

The widespread use of EOR and PS in developed fields, where the share of HTR reserves reaches 70–75%, is becoming the main and non-alternative way to increase oil recovery and requires further scientific research in the field of substantiating the optimal conditions for the construction and operation of development systems.

References

Astafiev V.N., Samoilov M.I. (2015). Development of hard-to-recover hydrocarbon reserves: high-speed multi-stage hydraulic fracturing of the Tyumen suite of the Em-Egovskoye field. *Inzhenernaya praktika*, (5). (In Russ.)

Brekhuntsov A.M., Monastyrev B.V., Nesterov I.I. Jr. (2011). Distribution patterns of oil and gas accumulations in West Siberia. *Russian Geology and Geophysics*, 52(8), pp. 781–791. https://doi.org/10.1016/j.rgg.2011.07.004

Dolgov M.F. (2021) Analysis of the effectiveness of the use of flow diverting compositions in the field N. *Nauchnyy elektronnyy zhurnal Meridian*, 4(57), pp. 177–179. (In Russ.)

Isaev V.I., Kuzmenkov S.G., Ayupov R.Sh., Kuzmin Yu. A., Lobova G.A., Stulov P.A. (2019). Hard-to-recover Reserves of Yugra Oil (West Siberia). *Geofizicheskii zhurnal*, 41(1), pp. 33–43.

Korkunov V.V., Novikov. M V., Kuzmenkov S.G. (2013). Missed opportunities in stabilizing the level of oil production. *Nedropol'zovanie XXI vek*, (4), pp. 36–39. (In Russ.)

Kuzmenkov S.G., Ayupov R.Sh., Novikov M.V., Isaev V.I., Lobova G.A., et al. (2020). Methods for enhanced oil recovery at Yugra fields. *Izvestiya Tomskogo politekhnicheskogo universiteta. Inzhiniring georesursov = Bulletin of the Tomsk Polytechnic University. Geo Assets Engineering*, 331(4), pp. 96–106. (In Russ.)

Kuzmenkov S.G., Isaev V.I., Bulatov V.I., Ayupov R.Sh., Igenbaeva N.O., Kuzmin Yu.A., Stulov P.A. (2018). Development of the oil and gas complex of Yugra, hard-to-recover reserves. *Izvestiya Tomskogo politekhnicheskogo universiteta. Inzhiniring georesursov = Bulletin of the Tomsk Polytechnic University. Geo Assets Engineering*, 329(11), pp. 103–113. (In Russ.)

Kuzmenkov S.G., Kuzmin Yu.A., Stulov P.A., Ayupov R.Sh., Bulatov V.I., et al. (2019). Identification of hard-to-recover oil reserves of Yugra. *Geofizicheskii zhurnal*, 41(4), pp. 114–124. (In Russ.)

Nanishvili O.A., Permin D.D., Samoilov V.R. (2019). Effectiveness analysis of complex effects of unsteady water-flooding combined with processing of water injection wells by flow diverting compositions at the "X" field. *Mezhd. nauchno-issled. zhurnal*, 4–1(82), pp. 72–77. (In Russ.)

Orenburkin A.V., Galkin N.Yu., Maryina N.D., Kozelskaya N.V. (2019). Comparison of the production of oil reserves by the main subsoil users of the Khanty-Mansi Autonomous Okrug – Yugra. *Ways to realize oil, gas and ore potential of KhMAO – Yugra: Proc. 22 Sci. Conf.* Khanty-Mansiysk: IzdatNaukaServis, pp. 44–52. (In Russ.)

Polukeev S.M., Shpilman A.V., Kuzmin Yu.A., Korkunov V.V., Novikov M.V., Kuzmenkov S.G. (2013). Stabilization of oil production in Yugra at the expense of hard-to-recover reserves – myth or reality? *Nedropol'zovanie XXI vek*, (5), pp. 12–19. (In Russ.)

Tolstolytkin I.P., Mukharlyamova N.V., Pecherin T.N., Strelchenko M.V. (2019). Estimation of the production potential of oil fields in KhMAO – Yugra in modern conditions. *Ways to realize oil, gas and ore potential of KhMAO – Yugra: Proc. 22 Sci. Conf.* Khanty-Mansiysk: IzdatNaukaServis, pp. 15–23. (In Russ.)

Vodyasov, K. O. (2022). The main directions of renovation of the oil and gas complex of Yugra. Problems of geology and subsoil development: *Proc. XXVI Int. Symp. named after Academician M.A. Usov of students and young scientists*, Vol. 1. Tomsk: National Research Tomsk Polytechnic University, pp. 110–112. (In Russ.)

Zakharova N.P., Zagidullin M.I. (2015). Analysis of the effectiveness of the use of non-stationary waterflooding in combination with targeted treatments of injection wells with diverting compounds. *Nauchnyy forum. Sibir'*, (1), pp. 37–40. (In Russ.)

About the Authors

Stanislav G. Kuzmenkov – Dr. Sci. (Geology and Mineralogy), Professor, Higher Oil School, Yugra State University

16, Chekhov st., Khanty-Mansiysk, 628012, Russian Federation

Maksim I. Korolev – Cand. Sci. (Engineering), Associate Professor, Higher Oil School, Yugra State University

16, Chekhov st., Khanty-Mansiysk, 628012, Russian Federation

Maksim V. Novikov – Deputy Director, Department of Subsurface Management & Natural Resources of Khanty-Mansi Autonomous Okrug – Yugra

2, Studencheskaya st., Khanty-Mansiysk, 628007, Russian Federation

Alexandra N. Palyanitsina – Cand. Sci. (Engineering), Associate Professor, Department of Development and Operation of Oil and Gas Fields, Saint Petersburg Mining University

2, 21 line Vasilievsky Island, St. Petersburg, 199106, Russian Federation

Olga A. Nanishvili – Senior Lecturer, Higher Oil School, Yugra State University

16, Chekhov st., Khanty-Mansiysk, 628012, Russian Federation

Valery I. Isaev (1952–2023) – Dr. Sci. (Geology and Mineralogy), Professor, Department of Geology, School of Earth Sciences & Engineering, National Research Tomsk Polytechnic University

30, Lenin ave., Tomsk, 634050, Russian Federation

Manuscript received 15 May 2023;
Accepted 4 August 2023; Published 30 September 2023

IN RUSSIAN

Эффективность применения методов повышения нефтеотдачи пластов и интенсификации добычи нефти на месторождениях Ханты-Мансийского автономного округа – Югры

С.Г. Кузьменков[1], М.И. Королев[1], М.В. Новиков[2] , А.Н. Паляницина[3], О.А. Нанишвили[1], В.И. Исаев[4]*

[1]Югорский государственный университет, Ханты-Мансийск, Россия
[2]Департамент недропользования и природных ресурсов Ханты-Мансийского автономного округа – Югры, Ханты-Мансийск, Россия
[3]Санкт-Петербургский горный университет, Санкт-Петербург, Россия
[4]Томский политехнический университет, Томск, Россия
[*]Ответственный автор: Станислав Григорьевич Кузьменков, e-mail: ksg.1948@yandex.ru

Установление добычи нефти на уровне 215–220 млн т/год, а также ее последующий рост – это приоритетная задача для предприятий топливно-энергетического комплекса Ханты-Мансийского автономного округа – Югры (ХМАО – Югры). Добиться этого невозможно без активного внедрения наиболее эффективных современных технологий повышения нефтеотдачи пластов. Настоящая статья ставит своей целью проанализировать применяемые на месторождениях ХМАО – Югры в промышленных масштабах методы повышения нефтеотдачи пластов и интенсификации добычи нефти (МПНП и ИДН), их особенности и их вклад в дополнительную добычу нефти с 2001 по 2021 г.

В статье описаны такие технологии, как зарезка боковых стволов (ЗБС), физико-химические методы (ФХМ), гидроразрыв пласта (ГРП), обработка призабойной зоны (ОПЗ), гидродинамические методы (ГДМ), бурение горизонтальных скважин (БГС), а также другие геолого-технические мероприятия (ГТМ), направленные на оптимизацию работы скважин (прочие ГТМ). Проведенное исследование показало, что наиболее применяемыми стали ФХМ, ОПЗ и прочие ГТМ. Доля дополнительно добытой нефти за счет применения МПНП и ИДН выросла с 2013 г. вдвое: 8 % в 2013 г., 16,2 % в 2021 г. Наибольшую эффективность показали ГРП, БГС и ЗБС. Всё это привело к стабилизации годовой добычи нефти в ХМАО – Югре и даже к ее росту в 2021 г.

Особенно актуально применение методов увеличения нефтеотдачи на безальтернативной основе у разрабатываемых месторождений, потому что доля трудноизвлекаемых запасов высока и достигает 80% по некоторым компаниям ХМАО – Югры. Для таких месторождений требуется усиления научных исследований в области обоснования оптимальных условий строительства скважин, а также эксплуатации систем разработки.

Ключевые слова: трудноизвлекаемые запасы, коэффициент извлечения нефти, метод повышения нефтеотдачи пластов, интенсификация добычи нефти, ретроспективный анализ, Ханты-Мансийский автономный округ – Югра

Для цитирования: Кузьменков С.Г., Королев М.И., Новиков М.В., Паляницина А.Н. , Нанишвили О.А., Исаев В.И. (2023). Эффективность применения методов повышения нефтеотдачи пластов и интенсификации добычи нефти на месторождениях Ханты-Мансийского автономного округа – Югры. *Георесурсы,* 25(3), с. 129–139. https://doi.org/10.18599/grs.2023.3.16