SOLVING THE FUNDAMENTAL PROBLEMS OF THE RUSSIAN OIL INDUSTRY IS THE BASIS FOR A LARGE-SCALE TRANSITION TO INNOVATIVE DEVELOPMENT

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Abstract. The powerful technical progress in the West in studying and developing deposits of unconventional hydrocarbons has a great influence on increasing the efficiency of conventional oil and gas deposits. Based on the foundation of modern oil science, it is necessary to calculate reserves and carry out design taking into account geological, off-balance and recoverable reserves. The necessity is substantiated of an innovative approach for the whole chain of hydrocarbon fields exploration and development, the new ideology of construction of geological and hydrodynamic models, the transition to a new level of calculation of development indicators and the oil recovery factor. Particular attention is paid to the improvement of development systems based on various categories of horizontal and multi-hole wells and the application of various fracturing technologies in hard-to-recover oil reserves and tight reservoirs, the selection of new technologies, and pilot commercial development in the field.

Keywords: reserves, tight rocks, hard-to-recover oil reserves, unconventional oil deposits, oil recovery factor, EOR, hydraulic fracturing, horizontal and multistage wells
DOI: https://doi.org/10.18599/grs.19.3.1

For citation: Muslimov R.Kh. Solving the Fundamental Problems of the Russian Oil Industry is the Basis for a Large-Scale Transition to Innovative Development. *Georesursy = Georesources*. 2017. V. 19. No. 3. Part 1. Pp. 151-158. DOI: https://doi.org/10.18599/grs.19.3.1

The powerful technical progress in the West in studying and developing deposits of unconventional hydrocarbons has a great influence on increasing the efficiency of conventional oil and gas deposits. Based on the foundation of modern oil science, it is necessary to calculate reserves and carry out design taking into account geological, off-balance and recoverable reserves. The necessity is substantiated of an innovative approach for the whole chain of hydrocarbon fields exploration and development, the new ideology of construction of geological and hydrodynamic models, the transition to a new level of calculation of development indicators and the oil recovery factor. Particular attention is paid to the improvement of development systems based on various categories of horizontal and multi-hole wells and the application of various fracturing technologies in hard-to-recover oil reserves and tight reservoirs, the selection of new technologies, and pilot commercial development in the field.

A feature of the current development stage of the oil industry is that until now, science has dealt mainly with the problems of involving deposits with hard-to-recover oil reserves in active development. This problem also remains one of the most important for the future. But this is not enough for the further development. New directions of the world development for the hydrocarbon branches of the fuel and energy complex require solving the problems of development of unconventional objects – deposits of heavy oils and natural bitumen, deposits in shale and similar sediments, and, in general, in tight rocks. The resources of heavy oils and natural bitumen in the world are comparable to the resources of conventional oils. The same situation exists in the Republic of Tatarstan.

Oil-gas-containing tight rocks in nature are much more than conventional reservoir rocks, which is due to the conditions of sedimentation and subsequent conversion of sediments. This is evidenced by the already available data on the resources of conventional oils and liquid hydrocarbons in tight and shale sediments. To assess the oil reserves in tight and shale rocks, specific types of research are needed, and their extraction require for technologies that are fundamentally different from the extraction methods for reserves that are difficult to recover.

Along with the new directions, the old problem remains to ensure the effective development of the so-called active reserves (or standard according to the western terminology) of long-developed highly productive fields. Here the design oil recovery factors reach values of 0.4-0.45 and, rarely, 0.5 and higher. The increase in oil recovery at these facilities to the values of displacement efficiency is the highest priority for the old oil producing regions.

The above-mentioned areas of development require solving the fundamental problems of the industry, both accumulated over the entire long history of the oil industry, and emerging again. Today, there is a need to assess the geological resources of oil, since balance and recoverable reserves, in the old, established understanding, leave behind substandard reserves, and they, according to preliminary estimates, may amount to 15-20 % of approved ones. At the same time, it is necessary to understand that geological reserves mean the entire amount of oil in the subsoil, regardless of whether it can be extracted from the subsoil today (Muslimov, 2016a). With this approach, the total resources will increase, and the oil recovery factor values will decrease. It seems advisable to develop a methodology for calculating geological reserves, taking into account the enormous progress in the West in the field of geological research and the available experience in extracting hydrocarbons from tight rocks (or even shales) (Prishchepa et al., 2014).

In modern conditions it is time to move to a new level of calculations of development parameters and oil recovery factor. To this day, thanks to the concept of absolute pore space, the initial petrophysical dependences are based on the results of mass determination of non-informative values of the absolute permeability coefficients for gas and open porosity (on dry cores). According to the concept of effective pore space, petrophysical dependencies must be built on the results of determining real effective permeability coefficients and effective porosity, because the degree of reliability of petrophysical dependences within the effective pore space concept is significantly higher than in the absolute pore space concept. Then it is obvious that the reliability of logging data for building 3D models will be much higher (Zakirov et al., 2006).

We must fundamentally change the ideology of constructing models, taking into account the allocation of geological, off-balance and recoverable reserves. Currently used methods of preparing information are not enough to build such models. First of all, it is necessary to significantly diversify and deepen laboratory studies of rocks and fluids that saturate them, and to improve logging methods (Muslimov, 2016a).

The foregoing obliges us to take a new approach to the stages of field development adopted in the 1970s (Ivanova, 1976). So far, we have also adhered to the identification of four stages of development of oil fields. But at the same time, the IV stage of development (in terms of significance in the formation of high oil recovery factor values and long development periods) was understood quite differently (Muslimov, 2012). But at present it is obvious that it is necessary first of all for the large fields to allocate also the V stage of development, which will mainly exploit the oil reserves previously not accounted for either in the official oil balances or in the accepted development projects (reserves in tight strata, earlier immobile reserves in operated facilities). With this in mind, a new stage of development is shown in Fig. 1.

All this is supported by modern achievements in the development of oil reserves in particularly complex geological conditions: tight (substandard) strata, highly watered long-term developed deposits. They include the technology of horizontal drilling, drilling of branched-horizontal wells, multi-hole wells, intermittent, directed hydraulic fracturing, the integration of horizontal wells with multistage fracturing, horizontal wells with wave methods, chemical compositions for producing highly watered strata, use of CO_2, pulsed-plasma method, etc. A number of these technologies (physical and chemical) have been created in the Republic of Tatarstan, and the rest are successfully used.

The next problem is the rationale for oil recovery factor and measures to increase it, which is very important for the late stage of development, where almost all the significant fields in Russia are located. The fact is that the entire huge volume of field, geophysical, hydrodynamic research, and analysis of constructing geological and hydrodynamic models was reduced to

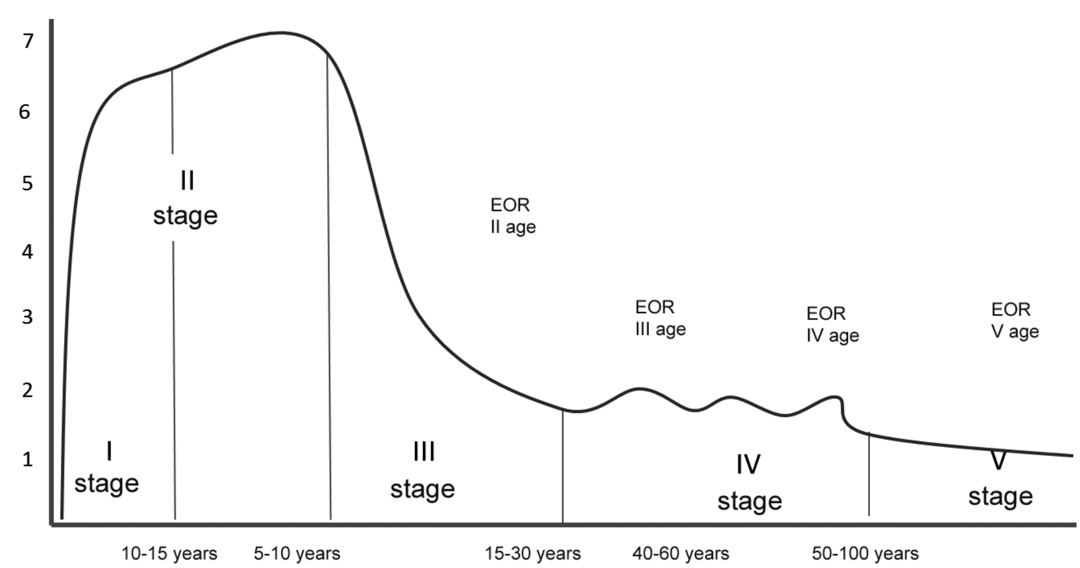

Fig. 1. Stages of development of the operational object (according to R. Kh. Muslimov)

determining the degree of water cut of the reservoirs and strata, and ultimately to determining the sweep efficiency Kokhv. At the same time, the displacement efficiency (Kv) determined by the primary calculation of reserves by laboratory methods was adopted. It is determined by injecting water through the core, or "infinite flushing of the formation" as written in all the textbooks. There was no doubt in the definition of Kv. But with the accumulation of experience in the development, we noticed that in washed areas in a number of cases very high Kv was obtained. When Kv was taken on these sites, according to laboratory data Kohv should have been close to unity and even more, which in conditions of really heterogeneous beds is impossible.

It has not been possible so far to solve the problem of reliable laboratory determination of Kv and its transfer to commercial conditions. A paradox turned out – we should probably have the maximum value of Kv ("infinite flushing") in cores, but in real layers it is bigger. An explanation for this is given in the work (Zakirov et al, 2009).

But the main reason in our opinion is fracturing, which in laboratory conditions cannot be identified, but in real layers it is the main factor of oil displacement. From here we can draw a fundamental conclusion: if in most cases we have an underestimated Kv, then we, in analyzing the oil recovery factor in the developed areas, overestimate Kohv, i.e. the main (not less than 80-90%) geological and technological measures in the fields are carried out according to this factor. To achieve the project oil recovery factor, it is necessary to increase the volumes of geological and technical measures to achieve the project Kohv. There is why we need to drill more wells and stimulate more the basin. This fundamentally changes the approach to design development, planning of geological and technical measures and practice development of deposits.

Currently, despite the formal updating of standards, design is essentially carried out at the level of the 70s of last century. The analogy method used by the authors of the projects (especially in geological and physical characteristics of the deposit), the imperfection of modeling methods and hydrodynamic calculations, ignoring conventional classical methods for solving development problems, the lack of a profound professional analysis of the reserves development, insufficient control and regulation of development processes is the way to the unknown. All these problems lead not only to a short "life" of projects, but also to dilution of oil reserves.

Based on the world trends in the development of the industry, development systems using a fundamentally new type of wells (horizontal and multi-hole wells of different configurations), various fracturing technologies, new methods of increasing oil recovery and treating the wellbore zone of the formation are the priority. The technologies of horizontal drilling with a modern complex of research equipment came to Russia from the West mainly due to the efforts of our compatriot A.M. Grigoryan.

In the last quarter of the last century, drilling of horizontal wells in the world developed at an unprecedented rate. Later this boom came in Russia. Various types and designs of horizontal, multi-hole, branch-horizontal wells, and later sidetracking in previously drilled (old) wells appeared. In the last quarter of a century, Tatarstan has accumulated extensive experience in the use of horizontal wells to develop hydrocarbon deposits. However, despite the long period of use of horizontal wells in the Republic, their efficiency is relatively low: the rates of horizontal wells are only 1.5-2.2 times higher than the rates of vertical wells. The main reason is the non-systematic application of horizontal wells and the consequent disregard for the principles of rational development of oil fields, established by 70 years of practice and theory of development of oil fields by vertical wells (optimization of allocating operational objects and wells spacing, technological regimes of rational well operation, separate stimulation on reservoirs with different permeability; control and regulation of oil displacement processes).

The experience of using horizontal wells showed that they alone do not ensure the complete coverage of the reservoir's reserves by drainage. The horizontal well itself, drilled by the common filter by the oil displacement coverage, differs little from the vertical well. In both cases, only a small part of the penetrated interval of the reservoir is operated. The greater the heterogeneity, the smaller the share of drained interval. To increase the sweep efficiency of the deposit, separation of intervals is necessary with permeability different from each other by 2-3 times or more.

But the experience of the Fedorovsky field in Western Siberia shows that in the most complicated geological conditions of oil and gas object AS4-8 (a small oil rim lying between gas cap and underlying water, an unfavorable ratio of the oil viscosity to the water viscosity is 13.6, high heterogeneity and dismemberment of layers) the use of traditional vertical well development systems can not provide sufficient current production levels and more or less acceptable oil recovery. The use of horizontal well development systems significantly increases current production and ultimate oil recovery (Muslimov, 2016c).

The need for a systematic approach to the development of fields with hard-to-recover oil reserves is evidenced by the experience of developing the Kizelian deposit of the Bavlinsky field. To solve the problem of rational development of the entire Kizelian deposit of the Bavlinsky field, it was decided to carry out pilot commercial development for the Korobkovsky section by the system of production horizontal wells and injection vertical wells using vertical-lateral waterflooding of S.N. Zakirov (Zakirov, 2009). Analysis of the prospects of this section with the further implementation of the projected technology until the end of the development with the water cut of 98% shows that it is possible to achieve the oil recovery factor of 0.369, and taking into account the correction of balance reserves (with the transition to geological) – about 0.3. This will be a real oil recovery factor, increased against the project one of 0.2 (Muslimov, 2016c, Zakirov, Zakirov, 1996).

Having remarkable results in the development of the Kizelian deposit of the Korobkovsky section, it is time to design such a system for the Kizelian deposit of the entire Bavlinsky field. It will allow to almost double the recoverable reserves of the deposit.

For the development of multi-layer, multi-level inefficient fields by a system of multi-hole horizontal wells it is necessary to have a fundamentally different geological model based on the fundamental positions of geology (Muslimov, 2017).

In general, further increase in the effectiveness of horizontal drilling is possible on the path of the most complete use of modern systems of rational development of oil and oil and gas fields developed during decades by vertical wells. These systems remain basic.

Horizontal wells expand the field of application of waterflooding in poorly permeable reservoirs (permeability of less than 1-5 mD), low-thickness (more than 10 m) oil rims in gas-oil deposits, thermal methods in deposits of highly and ultra viscous oils and natural bitumen. In such difficult conditions, horizontal wells are the most optimal, ensuring cost-effective operation. For the development of shale objects and generally tight rocks (permeability of less than a 1 mDa), the use of horizontal wells should be supplemented with methods that increase the reservoir permeability (hydraulic fracturing), as well as other methods of enhancing oil recovery (wave, thermogas, pulse-plasma, etc.). Industrial development of unconventional deposits in shale and tight rocks without the use of various modifications of horizontal wells at the current level of development is not possible at all.

In old oil-producing regions, which primarily include the fields of the Volga-Ural oil and gas province, the main fields have been drilled with sufficiently dense well spacing. Most of them are in the late stage of development. But there are great opportunities for involvement in the active development of the existing systems of reserves that are not developed by the existing ones, and even greater possibilities of extracting residual oil from the developed sites. On a multi-object multi-layer Romashkino field, despite more than 70 years of development, less permeable layers and interlayers and previously recognized substandard layers are not operated on a large area. Their development is possible with the use of lateral horizontal trunks and new stimulation technologies.

Currently, the efficiency of drilling lateral horizontal trunks in the Romashkino field is low due to the unresolved number of technical and technological problems, but the prospects for their application are very large.

Our analysis showed (Muslimov, 2014) that today, after a long development in this field, there are plots that are simultaneously developed on all four stages. The strategy for their further exploitation is given in Table 1.

The application of lateral horizontal trunks will allow developing weakly permeable layers from the II stage of development, carrying out pilot commercial development for the production of tight strata – from the I stage. Drilling lateral horizontal trunks on long-exploited fields (especially in the system version) will increase the oil recovery beyond the design level, and at inefficient multi-layer fields with reserves difficult to recover – will increase geological and recoverable oil reserves. This entails conventional deposits of oil.

In addition, the latest researches of particularly large fields in the context of both operated and non-operated objects predict the presence of oil in the so-called tight rocks or semi-reservoirs (Morozov et al., 2016). The work conducted by V.P. Morozov et al., has substantiated the presence of tight oil-saturated carbonate rocks among the studied sections, which have potential industrial oil content.

Thus, the sections studied by core of the lower and middle Carboniferous show that among the carbonate rocks in terms of the degree of oil saturation, we can distinguish:

- oil saturated rocks
- tight rocks without any signs of oil;
- tight oil-saturated rocks, intermediate between them (reservoir rocks).

Drilling of the lateral horizontal trunks will be necessary to determine the availability and potential of such reservoirs by carrying out pilot commercial development to extract oil from the exploited fields of Tatarstan. After assessing the possible productivity of tight strata in existing and new fields with the help of lateral horizontal trunks, there will be opportunities to design their development using development systems with horizontal wells. In all cases of oil reserves development of low-permeability reservoirs in conventional deposits and tight strata in unconventional deposits after drilling lateral horizontal trunks horizontal wells, the introduction of hydraulic fracturing remains the main element of the development system. From

Site (reserves) categories	Management objectives, development systems, technologies	Technical support
Sites (reserves) is tight reservoirs that are below the conditional values in the I stage of development	Development of reserves allocated as an independent development facility, intensive increase in oil production due to drilling of injection branched horizontal wells, if necessary, producing branched horizontal wells, areal systems, first-generation methods of enhancing oil recovery (fracturing, wave, local gasdynamic fracturing, possibly gas), flooding by reservoir water with reservoir temperature	Individual low-performance high-pressure pumps with adjustable capacity; Overflow of reservoir water from the underlying aquifers
Sites (reserves) in low permeable and highly productive clay reservoirs in the II stage of development	Ensuring and maintaining the maximum of oil production through the allocation of reservoirs into an independent facility, the completion of the design stimulation system: complex technologies of developing terrigenous reservoirs, recovery enhancement and buttonhole treatment methods of the 1st generation (fracturing, local gasdynamic fracturing, horizontal wells, multi-hole wells, wave, chemical methods), flooding with reservoir or sewage water with preservation of temperature	Individual high-pressure pumps, drilling of horizontal wells, multi-hole wells, special water preparation for water injection
Sites (reserves) in the III stage of intensive decline in production	The goal is to extract more oil, less water, unbundling of operational facilities, infill of well spacing, drilling of injection branched horizontal wells for separate stimulation on reservoirs, massive introduction of second-generation EOR (chemical, physical, microbiological, wave, complex), ASKU-VP, CES, BDN introduction.	Available technical equipment for development, ASKU-VP, second-generation methods of enhancing recovery, KES, BDN, perforation-depressive methods, modern technologies of horizontal drilling
Sites (reserves) in the IV (late) stage of development	Stabilization and growth of oil production due to intensive reservoir development due to the introduction of ASKU-VP, the massive application of the EOR of the third and higher generations with the transition to the forced fluid withdrawal in non-stationary, pulsed operation of wells with regular pauses for perforating the deposit	High-performance pumps for fluid extraction, KES and BDN, to equip the ASKU-VP, methods of enhancing recovery for highly watered areas (water cut - up to 98-99%)

Table 1

domestic oil companies OJSC Surgutneftegas is the most advanced in the use of hydraulic fracturing as an important element of development. The company has been actively carrying hydraulic fracturing since 1993 (Malyshev et al., 2004).

The basis for the successful mass application of hydraulic fracturing is the selection of objects and the active learning of advanced domestic and foreign experience, as well as the maximum adaptation of the technology for conducting it in the geological conditions of the selected objects. The objects are selected on the basis of generalized criteria that take into account the features of geological structure of the reservoir, the current state of its development, and technological capabilities of the fracturing. To improve the criteria in selecting sites for fracturing, continuous monitoring of operation of all wells with hydraulic fracturing and surrounding wells is carried out. Here, in strata with high thickness, a stepwise (intermittent) or selective fracturing is used with different schemes for disengaging the productive intervals.

Gas-oil zones with separating shields less than 4 m thick are not traditionally considered to be objects for hydraulic fracturing, since during its development in the process of cracking, there is a high probability of disruption of shield integrity and the appearance of interplastic overflows. At such facilities, Surgutneftegaz is successfully using the technology of screen-based hydraulic fracturing, based on the inclusion of a composition in the process fluid that fills the peripheral zones of the created crack and prevents the entry of water. The results of more than 70 completed works showed that the success of such fracturing exceeds 70%, and the average expected additional oil production is 7500 tons.

OJSC Surgutneftegas uses hydraulic fracturing as a system of cost-effective development of reserves difficult to recover. The most effective type of stimulation on the Jurassic and Achimovian deposits is the large-scale fracturing, which, due to the injection of a large amount of proppant (50-80 tons), allows the creation of an extended, highly conductive crack that covers the entire productive thickness of low permeable, highly dissected reservoirs. As a result, the deadlock and stagnant zones of the formation are unlocked, the sweep efficiency, drainage rate, residual oil saturation are significantly increased, as well as the oil recovery. The experience of such fracturing in the strata of the Achimovian and Jurassic deposits of the Bystrinsky field showed that the multiplicity of the increase in well production increases with the increase in the amount of proppant, and its values approach the corresponding values obtained for wells with flat and horizontal trunks that penetrate objects of a similar structure. Sometimes this leads to the fact that wells from the category of unproductive are transferred to the category of medium-productive ones. As a result, production from the facility as a whole becomes profitable.

In the Priobsky field, where without fracturing, the majority of wells have very low production rates (up to 5 tons/day), the fracturing increases them to 35-40 tons/day or more. Calculations of the designers showed that, without fracturing, the oil recovery factor for the main deposits would be 0.23, and with fracturing – 0.33. And for a number of fields in Western Siberia, hydraulic fracturing is used from the very beginning of putting the wells into operation. For such fields, the task of determining the technological efficiency of hydraulic fracturing is complicated because of the lack of a reference base. To do this, we have to resort to the analysis of production rates up to the fracturing along the wells of neighboring fields in terms of the geological structure of the field in question.

In highly permeable reservoirs, fracturing cannot be considered as a method of enhancing oil recovery. In this case, a method of accelerating the extraction of the projected amount of oil is used. Moreover, in certain geological conditions, this acceleration can lead to a significant decrease in oil recovery. The mechanism of this phenomenon is quite simple. Creating additional cracks in high-permeability reservoirs increases the natural inhomogeneity of the reservoir, which leads to an increase in the processes of uneven advance of injected water, premature watering of wells through artificially created cracks to the limiting value.

Therefore it is necessary to disconnect the well from the development and to leave oil reserves in a significant, unreached by flooding volume of the formation. In some cases, this process is less visible at the beginning, and may manifest itself at a late stage of site development. And in some cases this process manifests itself immediately. Thus, at the Upper Kolik-Egansky field, a fracturing at 44 wells of the reservoir of the Yu12-3 facility resulted in a sharp increase in water flooding. The watercut increased sharply from 21.8 to 48.6%.

However economically, hydraulic fracturing even under these conditions proved to be quite effective, and it seems that hydraulic fracturing was used on a weak permeable facility (according to available data, the permeability of the formation was 0.077 μm^2). But, apparently, these values are underestimated, as evidenced by the operation data of wells: high production rates before the fracturing (30-70 tons/day), observed fracturing effects on the rates of neighboring wells with a distance between them of about 400 m. Sufficiently exacerbating the negative impact of hydraulic fracturing on developing oil reserves was facilitated by unregulated development of the reservoir – the stationary injection of large volumes of water without its regulation.

With a more competent approach to the application of hydraulic fracturing, this method can give positive results. Thus, the hydraulic fracturing at the object BS10 of the Yuzhno-Yagunsky field allowed to increase oil production rates by 3-4 times while the watercut either remained at the same level, or even decreased.

The efficiency of hydraulic fracturing in Tatarstan is low, additional oil production per well is only about 3 tons per day. This is mainly due to geological conditions (depletion of the main fields, low productivity of small deposits). Here it is necessary to point out the unsatisfactory selection of wells and geological control over the works conducted. Suffice it to say that the rate of production is up to 1 ton/day in 30% of wells, from 1 to 3 tons/day – in 34% of wells, and only 36% of treated wells proved to be quite effective (the increase was from 3 to 10 tons/day).

But with a more competent approach to the application of hydraulic fracturing, even at sufficiently depleted objects at a late stage of development, good results are achieved. In Oil and Gas Production Department Almetyevneft at the Romashkino field, the average daily production rate for sand reservoirs averaged 4.6 tons per day for 6 years, and 2.1 tons per day for clay reservoirs. A multiple increase in production rates was obtained.

At the same time, the growth in the productivity factor was 2.9 times in the weakly permeable reservoirs, 3.3 – in clay reservoirs, 3.2 – in highly productive reservoirs, and 3.2 – on the average. Lower values of the increase in production rates (about 2) are explained by the unrealized production potential due to the lack of due attention to the improvement of the reservoir pressure maintenance system. The same can be said about the area application of hydraulic fracturing in the 2nd block of the Minnibayevsky area, when the increase in production was a maximum of 1.5 times – this is not enough due to the lack of a complete approach. However, for a late stage, even such a result can be considered acceptable (Gumarov et al., 2012).

Therefore, there are reserves for increasing the efficiency of hydraulic fracturing in the Republic of Tatarstan. But they will be even greater when combining fracturing with wave methods using technology developed under the guidance of Acad. R.F. Ganiev (Ganiev, 1998).

Even on geologically more complex (than in PJSC Tatneft) conditions of fields operated by small oil companies, an increase in oil production is on average

3 tons per day, and in some small oil companies – up to 4 tons per day. With a total average flow rate of about 2.5-3 t/day, this effect can be considered high.

The permeability values for classifying reservoirs as weakly permeable should be determined for each field based on pilot commercial development by the nature of the layers formation. But to determine the possibility of using hydraulic fracturing to develop such reservoirs, it is not enough only to know the permeability values; it is necessary to know the conditions of occurrence and hydrodynamics of oil deposits. Thus, the weakly permeable, highly dissected reservoirs of the Achimovian strata in the Western Siberia contain hard-to-recover oil reserves. Separate layers in the wells are poorly correlated with each other. However, the experience of hydraulic fracturing shows high efficiency. Obviously, this is due to the hydrodynamic connection of these layers among themselves and influence of fracturing.

On the contrary, at the Romashkino field, the weakly permeable layers of the D1D0 horizons are characterized by a very small dissection, although they are fairly well correlated with each other than the Achimovian deposits of Western Siberia. However, hydraulic fracturing here does not give positive results due to low reservoir pressures.

Based on the foregoing, it can be said that the fracturing in the Achimovian stratum is a typical high-efficiency method of enhancing oil recovery, and it is inefficient in the weakly permeable reservoirs of the Romashkino field without the organization of a reservoir pressure maintenance system.

In the most difficult conditions (unconventional reservoirs of Bazhenov deposits), OJSC Surgutneftegas, based on world experience, has conducted fracturing operations in horizontal wells and also in sidetracks with a horizontal face. Experience has shown that existing fracturing equipment can be used in horizontal wells – creating a crack increases the effective drainage zone of the formation.

The hydraulic fracturing method can be the only method in demand for the development of oil deposits in shale and similar rocks and, in general, in tight rocks with permeability of 1 mD and below. Without this method, the exploitation of such deposits is not even currently being discussed. After the fracturing, other methods of enhancing oil recovery can be used.

Today, we can consider the local gasdynamic fracturing of a reservoir created in KB-Avangard as an alternative to hydraulic fracturing. It is associated with the use of ZGRP-01-1 charges based on missile ballistic fuel, the combustion of which emits powder gases. They have a high-energy impulse effect, which leads to the formation of cracks in the bottomhole zone, cleansing of paraffin sediments, asphalt-resinous substances, products of chemical reactions, destruction of bottomhole zone contaminated in the drilling process, areas of colmatation, phase, water-oil and hydrodynamic barriers. The local gasdynamic fracturing does not need to be cured with proppant, much cheaper than conventional fracturing (6-10 times), and can be used in certain areas of exploited deposits with hard-to-recover reserves, and especially in conditions of contaminated bottomhole well zones. The same tasks can be performed by oscillators for treating wells under different names, such as borehole hydrodynamic oscillators.

Hydromechanical wave technologies of the new generation now unite one of the new and promising areas of engineering and technology developed for the first time in the world at the Scientific Center of Nonlinear Wave Mechanics and Technology (Academician R.F. Ganiev). The authors carried out in California tests and comparisons of this technology with the classical hydraulic fracturing. It is shown that the same efficiency is achieved both in fracturing, but with much lower costs.

In the Republic of Tatarstan at the end of the last century, almost all the methods of enhancing oil recovery and well stimulation used in the world were applied. Approximately 250 different technologies of enhancing oil recovery and bottomhole treatment of 30 basic methods were tested. A little more than 30 technologies are currently used for industrial implementation. Here, the main task is to ensure the selection of the most effective method of enhancing oil recovery and bottomhole treatment that are best suited to the specific geological and physical parameters of the deposits, based on the conditions for the effective application of specific method and their potential capabilities (Table 2).

It will make possible to test the stimulation system that is most adequate to the natural geological structure of the deposit. But all this should be done after choosing the optimal well spacing and operational objects of optimal size, providing a more complete drainage of the development facility. These are fundamental provisions, which can include the basic provisions of control and regulation, worked out in the fields over the past 50-70 years. And all the rest (horizontal, branched horizontal, multi-hole wells, sidetracking, dual completion, methods of oil recovery enhancement, bottomohole treatment, etc.) are the tools for rational production of hydrocarbon reserves.

The interests of the government in terms of filling the budget are more “short-term” in comparison with the “long-term” interests of society. For the subsoil user, high profits and a faster payback of costs are needed, and for the people – long-term earnings from the development of the field (greater oil recovery factor). Therefore, in general, optimization of production and maximization

Working agent	Increase in oil recovery, %	Critical factor of working agent application
Water + gas	5-10	Horizontal separation. Decreased productivity
Polymers	5-8	Salinity of water and reservoir. Decreased productivity
Alkalis	2-8	Oil activity
Micellar solutions	On to 8	The complexity of technology. Salinity of water and reservoir. Decreased productivity.
Gas methods of enhancing recovery	8-15 (Oil recovery factor for CO2 injection can grow up to 55-60%)	Loss of heat. Shallow depth. Removal of sand. Technical problems.
Steam	15-35	Loss of heat. Shallow depth. Removal of sand. Technical problems.
Air + water (VG)	15-30	Complications at initiation. Low coverage by burning. Technical problems. Unsatisfactory environmental protection.
Development systems with horizontal wells	20-30	Detailed study of the geological structure features
The newest physicochemical methods of enhancing recovery	8	Sufficient injectivity of injecting wells and permeability in producing wells.

Table 2

of oil recovery factor is needed. This should be done at the design and examination stage of documents for the development of the field on the principles of rationality (Muslimov, 2016b).

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Manuscript received 5 June 2017;
Accepted 14 July 2017; Published 30 June 2017