Influence of Geologic and Technological Measures on the Effectiveness of Wells during the Exploitation of Krasnoleninsky Field

I I Krasnov¹, E I Inyakina², R K Katanova¹

¹FSBEI HE North-Eastern Federal University. M.K. Ammosova, Polytechnic Institute (branch), 5/1 Tikhonova Str., Mirny, 678175, (Sakha) Yakutia
²FGBOU VO Tyumen Industrial University, 36 Volodarskogo Str., Tyumen, 625000, Russia

E-mail: rose941101@mail.ru

Abstract. This article assesses the prospects for the use of geological and technical measures related to the creation of non-traditional methods. The essence of which is not only high manufacturability, but also energy saving with a significant expansion of geological criteria for their applicability. Hydraulic fracturing is widely used in wells operating an oil reservoir, which in most cases is proved theoretically and practically. According to the results of geological field analysis, it was found that for the conditions of development of deposits of the Krasnoleninsky field, the introduction of hydraulic fracturing into wells is a tool, the reuse of which, regardless of the current water cut, will help to increase the productivity of production wells. A further increase in the efficiency of work is associated with their complex organization in a reasonable combination of well operating modes, hydraulic fracturing technologies, and optimization of the waterflooding system.

1. Introduction

Exploitations of tight oil fields is a highly important problem for the nearest future. Evaluation of geologic and technological measures and influence on the productivity of wells using non-traditional methods is linked to the creation of not only high technological effectiveness, but energy-saving as well. Recently hydraulic fracturing is being applied on the wells. The effectiveness of the given technology in most cases has been proven in theory and in practice, however, ready to use solutions are hard to discover [1,2].

At the moment, as parts of Krasnoleninsky field, Tallin, Em-Egovskaya, Palyanovskaya, Kamennaya, Inginskyaya, East-Inginskyaya, Sosnovo-Mysskaya Lebejya and a number of other areas stand out. Based on the results of seismic research, structural maps were compiled on the base reflecting horizons B and A, local elevations were identified, promising in oil and gas perspective. Result of this research is a making of structural maps on reflectors A, T, B, M1 and G, their specification, elaboration of the structure of productive complexes. Prospecting work proved the necessity of unification of identified (in accumulations of Tyumen suite) oil deposits into a Krasnoleninsky field [3,4].

In geological structure of a deposit various complexes of rock: from Pre-Kembrian to Quaternary inclusive. In composition of formations of bedrock Riphean, Paleozoic (from Ordovician to
Carboniferous (inclusive) and Triassic rock were discovered. They constitute several formational complexes, each of those reflecting a certain tectonomagnetic stage. Pre-Kembrian formations, constituting the lower structural level, are in conjunction to the spinal part of Shaim-Antorsky anticlinorium. They are represented by biotite, chlorite-sericite, clay-sericite, quartz-graphite, quartzite-sericite shale and amphibolites. Paleozoic formations (second structural level) are represented by less metamorphized rock. They are more often developed on the wings of anticlinoriums and synclinoriums. Low- Paleozoic rock are more metamorphized and represented by various types of shale and quartzite. Mid-Paleozoic formations are folded by the rock of devon and lower carbon. Devon complexes are represented by volcanogenic and volcanogenic- sedimentary rock. They constitute diverse porphyrites, which occur among metamorphized sandstone, sand-clay and phyllite shales. Low-laid coal deposits are exposed on the slopes of the neighbouring Shaim megaswell. They are folded by dark-gray, often carbonaceous shales, which contain layers of sandstones and sand-clay shales. Upper-Paleozoic formations are represented by metamorphized dark-gray and greenish-gray siltstones, mudstones with interbeds of sandstones, less often gravelites. Paleozoic shales and intrusive rock which penetrate them are often exposed to secondary changes – hydrothermal exposure and weathering. The strength of the rock, changed by the secondary processes, reaches the first dozens of meters. Diorites and biotite granites, and their transitional varieties. The foundation of Krasnoleninsky oil area in tectonic sense has the 2-storeyed structure: lower one is a folded foundation proper and the upper one is composed of effusive sedimentary rocks of the Turin series, formed in the conditions of paraplates of the formed regime. Upper Mesozoic-Cenozoic structural tectonic floor is characterized by it’s weak placement and total lack of rock metamorphism and is a typical platform, formed in the conditions of prolonged steady submersion of the foundation. Deposits of Mesozoic- Cainozoic age contain main industrial accumulations of oil. Most of the researchers note the erosion-tectonic nature (dissection) of the relief of pre- Jurassic formations at the beginning of shaping of Mesozoic- Cainozoic platform mantle, considement growth of dome-shaped structures, which is linked to the multidirectional differentiated tectonic movements. In the foundation according to the geophysical data a dense network of different fractures is registered, including the subsurface ones. Subsurface fractures follow two directions: submeridional and sublatitudinal.

Thus, dome in the modern structural sense is tectonic element with regional decline of the slopes in the eastern direction, closer to the Khanty-Mansiysk depression. From the north-east the dome is separated from the positive adjoining structures with the same rank by the Elizarovsky megasag, and from the north-west neighbors with Sherkalinsky monocline. Mutom basin is separating the Krasnoleninsky dome from the west. From the south it is jointed with Shaim megaswell by Pottym saddle. On the roofing of the pre-Jurassic foundation (reflecting horizon “A”), within the boundaries of the Krasnoleninsky dome proper, a number of second-order structures are distinguished: the Endyr, Potymetsky, Sosnovsky and Srednenazym dome-shaped elevations, as well as the Talinsky and Galyanovsky swell. Endyr and Potymetsky elevations are separated by the Kalmanovsky sag. Each of these structures is complicated by several local elevations. Krasnoleninsky field is situated in the oil area of the same name of Frolov oil and gas oblast. The industrial oil-bearing capacity is connected to the deposits of Vikulovskaya (bed BK1), Abalakskaya (bed ІOK), Teyumen (bed ІOK2-9), Sherkali (beds ІOK-10,11) suites and pre-Jurassic complex (PJС). The most productive are the oil deposits connected to the deposits of beds ІOK-10 and ІOK-11 of the Sherkalinskaya suite of the Lower Jurassic age, lying unconformally on the rocks of the pre-Jurassic formation.

Based on the analysis of all geological and geophysical materials, a principal geological model of the predicted oil-bearing capacity of the productive section of the pre-Jurassic rock complex was built. A fairy clear connection of the zones of collector development to the sides of the Talinsky graben-like sag is observed. Moreover, in the south of the area, oil deposits are distributed along the left side of the Talinsky sag, and next, after the fracture (which crosses the plot area submeridionally), oil-saturated deposits distributed along the right side of the sag. Water saturated collectors are confined to the most submerged sections of the Talinsky sag. According to the analysis of the chemical composition of the waters of the Paleozoic sediments, it can be assumed that in some parts of the Talinsky area there is a
hydrodynamic connection with the overlying sediments of the Sherkala Formation. The boundaries of the deposits are rather arbitrary, since the patterns of collector distribution in pre-Jurassic formations within the Talinsky area have not yet been established. Oil production rates during testing of collectors in crust of weathering deposits vary from fractions of cubic meters per day (well №20013) to 40-80 tons per day (well №20033r) [5-8].

Due to the lack of hydrogeological data on the first and second water-bearing horizons of the Talinsky area, an analysis was made of the hydrogeochemical conditions of the given the water-bearing horizons of the Em-Yegovskaya area of the Krasnoleninsky field. The temperature of frozen rocks is close to the point of phase transitions of ice into water (the first tenths of a negative degree). Frozen rocks represented by sand varieties are of low ice with a massive cryogenic structure, and argillous rocks are in a frost-moldable state.

The results of a laboratory study of the filtration-capacitive properties on the core showed the absence of collectors with intergranular porosity in the pre-Jurassic complex. All studied samples turned out to be poorly permeable, despite the wide range of changes in their material composition and porosity. It is hardly possible to trace the patterns of lithological change in rocks only according to core data, either due to an incorrect primary description of it (the exact name of the rock can often be established only by petrographic studies) and due to the significant distance between the wells in which it was taken. According to some authors, according to well logs performed in production wells, a change in lithological composition can occur at a distance of less than 0.5-0.6 km.

The composition, physicochemical properties of oils and gases dissolved in it were studied from deep samples. According to the results of studies, the properties of oils have significant differences in values of gas content and, consequently, in oil densities and volumetric coefficients. The component composition of crude oil varies slightly in all considered horizons. Thus, the methane content varies from 33.45% to 37.79%, the amount of light hydrocarbons of the composition C_2H_6-C_3H_12 ranges from 22.69% to 29.79%. Normal butanes and pentanes prevail over their isomers. Molecular masses range from 84.54 to 93.67. Petroleum gas of standard separation is high-fat, the fat ratio is in the range of 48.66-76.35, the methane content is from 55.31% (bed IOK10) to 65.72%. The ratio of ethane to propane is less than one, typical for dissolved gases in oil deposits. For individual wells, this ratio exceeds 1.0, which is acceptable for high-fat gas, since this gas does not have other properties of gas condensate. The content of carbon dioxide is 1.59-2.11%, nitrogen 0.71-0.96%. The amount of light hydrocarbons CH_4-C_2H_12 dissolved in degassed oils is 10.47-11.34%. The oils of the studied beds of Jurassic deposits are low-sulfur, sulfur content 0.21-0.43%; slightly resinous, silica gel resins 2.03-3.64%; paraffin, with a paraffin content of 2.85 to 3.74%. Low-viscosity oils, kinematic viscosity at 20 °C 3.21-8.59 mm2/s, with a yield of light fractions up to 350°C more than 55% by volume. Ultra-fresh waters with mineralization values equal to 0.02-0.03 g/l. According to the chemical composition, waters are bicarbonate magnesium and magnesium-calcium. To forecast the use of ground waters of quaternary sediments for the purpose of RPM, additional hydrogeochemical and hydrodynamic parameters of the samples are required.

In the process of industrial development, in accordance with the refinement of the geological structure, the accumulation of engineering experience, fundamental project decisions and technological indicators were corrected, which was reflected in the project documents. Currently, the field is being developed on the basis of the “Technological scheme for the development of the Krasnoleninsky field”, based on the newly approved hydrocarbon reserves in the State Reserves Committee of the Russian Federation. The breakdown of the IOK10 facility was carried out by wells within a four meter isopach along a triangular grid with a distance between the wells of 600 m (grid density – 26 ha/well). The development system is seven-point reversed. The object of the pre-Jurassic complex - drilling of wells was carried out on a square grid with a distance between wells of 700 m (grid density – 49 ha/well). The development system is a seven-point reversed system with a subsequent transition to a five-point system, achieved oil recovery ratio – 0.374, with an approved – 0.374. Noteworthy are the small volumes of oil production and the progressing water encroachment of well production in the period preceding the third stage of field development. Indirectly, this fact
indicates an unfavorable structure of oil reserves, in which the part of actively drained reserves is very small. The subsequent rapid decline in oil production is typical only for the dynamics of the development of highly productive collectors, in case of when the reserves of low-permeability collectors are not involved in the development.

The decrease in the efficiency of well drilling is associated both with intensive water encroachment of highly productive beds and with the imperfection of the technologies used in the separation of oil and aquifer ranges. By the end of the third stage of development, the rate of selection from initial recovered reserves decreased to 0.9% or amounted to 31.4% of initial recovered reserves with a water cut of 93.3%. Since 1997, the field has entered the fourth stage of development, characterized by stabilization of the rate of decline in oil production and water cut in well production. This requires large-scale conducting of geological and technical measures, both on the existing and inactive well stock.

2. Revelance
Arrangements for intensification of the inflow through the use of hydraulic fracturing at the Krasnoleninsky field began in 1996. During this period, hydraulic fracturing was carried out by service companies: Katkoneft, Halliburton, Schlumberger, SPI, Frackmaster, Newco. Additional oil production from the activities carried out on hydraulic fracturing (according to the reporting of JSC «TNK-Nyagan» obtained in the first year after the work) amounted to 1962.6 thousand tons. Overall in the oil field, in 83.1% of cases, the object of hydraulic fracturing is operating wells of the ЫК10 beds. The conducted analysis of the implementation of hydraulic fracturing at the beginning of 2018 in the wells operating the ЫК10 oil deposits in order to determine the specific efficiency was determined as the ratio of the additional oil production from the work to the number of processed wells. Analyzing the specific efficiency results over the years, it is clear that the best results were achieved at the initial stage of the implementation of hydraulic fracturing technology, when the candidates for a well were selected more thoroughly than in subsequent years. The dynamics of specific efficiency is rapidly falling from the level of 7.5 noted in 1996 to the level of 1.6 as early as the following 1997. In subsequent years, good performance results were noted in 1998 and 2006, with levels of 2.6 and 2.4 thousand tons per well, respectively. From 2009 to 2015, this figure does not exceed 1.8 with a minimum value of 1.2. All this suggests that the operations of recent years have significantly lost in efficiency, most likely due to the exhaustion of suitable wells for hydraulic fracturing technology [9,10].

3. Formulation of the problem
In this regard, a need arose to review both the technology of the activities and the ideology of selecting wells for hydraulic fracturing. Therefore, the company "RN-Nyaganneftegaz" decided to introduce the technology of hydraulic fracturing of a "new design". The difference between the “new design” technology and the “old design” hydraulic fracturing technology is as follows: according to the “old design” technology, up to 20 tons of proppant were pumped into the formation, which caused cracks as narrow as 4.0–5.0 mm wide and as long as 70 meters to be created in the formation; according to the “new design” technology, cracks were created in the formation with width of 5.0–7.0 mm and length of 30–40 meters. The proppant consumption using the “new design” technology ranged from 20 to 50 tons. Proof of the greater effectiveness of this hydraulic fracturing "new design" are the results obtained from the wells. Thus, the input average oil flow rate increased almost twofold (from 7.7 tons/day to 15.2 tons/day). The specific effectiveness of hydraulic fracturing increased by 3 times compared to the previous period. Over the current period, the specific efficiency per well operation during hydraulic fracturing is almost stable - from 1.2 to 1.8 thousand tons/well, exceeding the values with a level of 0.9.
4. Theoretical part
In order to study the impact of geological and technical measures on the productivity of wells, an analysis of the available geological, geophysical and field information was carried out. As an object of research, the ЮK 10 oil reservoir was considered, within which the bulk of the work on hydraulic fracturing was performed, which is 71.7% of the total amount of work. Anticipating the analysis of the work performed, it is necessary to note some characteristic features of the geological structure of the formation, and the situation, established with the development of the field. The geological and geophysical characteristics of the formation are at first glance very favorable for their effective exploitation: significant thicknesses of up to 25 m, fairly high permeability values (core – 60.2 mD, well logging - 110.3 mD), moderate clay content in the intervals of the section. At the same time, significant heterogeneity of the productive beds in terms of permeability should be noted: the range of changes in the filtering properties of the collector is very wide (from 1 to 1050 mD), the coefficient of variation is 1.55. Thus, in the section both low permeability layers and sections of the “super collector” with high filtration properties are found. With a high value of current water cut reaching 90.6%, the amount of oil recovery from the initially drawn reserves slightly exceeds 45%. With low recovery rates (0.96%) from initial recovered reserves, the current oil recovery rate is only 14.6%. The situation remains unfavorable with the use of a drilled wells stock, of which only 29% are in the category of operating ones. The presence in the section of collectors with anomalously high filtration-capacitive properties, which has signs of a hydrophobic environment, high water cut of production - all these factors under normal conditions are arguments against the use of hydraulic fracturing, because they create the prerequisites for the deterioration of the dynamics of water encroachment of the wells, i.e. should have a negative impact on productivity of wells. The established practice of selecting wells for hydraulic fracturing distinguishes only those in which the water content in the product is low and the collectors can be put into the low or medium permeable class. According to geophysical and field information, the number of wells that satisfy such requirements is minimal. As it’s evident, the average permeability for wells with hydraulic fracturing is in the range of even higher values than overall values in the whole stratum. The distribution of wells by averaged permeability intervals is presented in Figure 1.

Research data on the distribution of wells by water cut before carrying out the measures show that more than half of the wells (63.5%) before well operations had a water cut of more than 50 percent. All the results presented indicate that the principle of selecting wells - candidates for work characterized by less favorable productivity and low water content of the products was not the determinative one. If collectors of the formations were typical, such a selection of wells for hydraulic fracturing should have led to unfavorable results. However, as field practice proves, this does not occur. In order to obtain objective results, it is important to limit the impact of external factors affecting the effectiveness of activities. The effectiveness was evaluated according to the following criteria:

- based on a comparison of the technological parameters of the wells before and after the activities, the increments of oil and liquid production rates, the change in the water cut of the well production were calculated;
- the dynamics of indicators were being analyzed, the rate of water encroachment in the subsequent period and the duration of the effect were studied;
- predicted volumes of oil production were calculated based on the characteristics displacement. of the displacement.
5. Practical significance

One of the features in carrying out the works is the significant periods of idle time of wells, which imposes very significant restrictions on the possibility of a quantitative assessment of their effectiveness. About 30% of the wells had not been operated before carrying out the geological and technical measures for various reasons up to five years; 34.6% of the wells had been inactive for more than 10 years. In this regard, the “mechanical” comparison of well exploitation behaviour in the periods preceding and following the work is not an objective reflection of the success of the technology used. Therefore, to assess the effectiveness of hydraulic fracturing, a group was identified that had a history of exploitation immediately preceding the start of the work. The distribution of wells that had been idle before to the start of the work on them is shown in Figure 2 according to periods of downtime.

Figure 1. Distribution of wells by averaged permeability intervals.

Figure 2. Distribution of wells that had been idle before the start of the works, arranged by periods of downtime.

The results of geological and technical measures for groups of wells with varied proportions of watering in the produced output are shown in table 1.
Table 1. Evaluation of the results for groups of wells with varied watering.

| Parameters                                      | Unit of Watering, % | Total  |
|------------------------------------------------|---------------------|--------|
| Number of wells                                 | pcs                 | 136    |
| Средняя эффект. и/н толщина                     | m                   | 14.2   |
| Average permeability                            | milli Darcy         | 72.9   |
| Average porosity                                | %                   | 0.15   |
| Average coefficient of grittiness               | fract. units.       | 0.44   |
| Average number of permeable intervals units     |                     | 6      |
| Average oil production                          | ton/day             | 4.7    |
| Before hydraulic fracturing                     |                     | 12.6   |
| After hydraulic fracturing                      |                     | 46.5   |
| Average liquid production                       | ton/day             |        |
| Before hydraulic fracturing                     |                     | 12.6   |
| After hydraulic fracturing                      |                     | 46.5   |
| Average permeability                            | %                   | 64.1   |
| Before hydraulic fracturing                     |                      |        |
| After hydraulic fracturing                      |                      |        |
| Average additional oil production               | thousand tons/well  | 3.380  |
| Duration of the effect average per a well       | months              |        |
| Studies of the tendencies in the dynamics of well parameters after hydraulic fracturing revealed a rather impressive fact. Compared to a group of low-watering production wells, a group of high-watering production wells is characterized by a longer duration of the effect, as well as a maximum rate of increase in oil production. The volumes of additional oil production, despite the minimum value of the starting flow rate, are almost the same. An important feature of this group is also a decrease in the proportion of water in well production from 87.3 to 81.1%. The decreasing nature of watering observed in this case is a reflection of the process of involving previously undrained oil reserves into the development. The given dynamics of the well performance parameters for the selected groups of wells with different water contents in the well output at the time of the work is presented in Figure 3.

According to the results of a statistical analysis, out of 136 wells stimulated by hydraulic fracturing, 28.7% watering decreased, including 13.2% of the wells, which had been exposed to watering by more than 80% before hydraulic fracturing, and at the same time there was no instant increase of watering in any well to the limit value [11,12,13].
Figure 3. Dynamics of the well performance parameters for the groups of wells with different water contents in the well output.

a) less than 50%; b) 50-80%; c) more than 80%

6. Conclusion

Thus, already at the first stage of the analysis of the results of hydraulic fracturing, it was established that the current effect of this measure has two components - an increase in well production and an increase in oil recovery coefficient, as evidenced by the fact of a decrease of watering in production. According to the results of the geological field analysis, it was revealed that for the development conditions of the ЮК10 formation of the Krasnoleninsky field, the implementation of hydraulic fracturing in wells is the tool whose repeated use, regardless of the current water cut of the production, will facilitate the movement of blocked oil to the bottom of production wells.

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