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ANALYSIS OF THE DIRECTIONS FOR IMPROVING THE DEVELOPMENT SYSTEMS FOR OIL FIELDS AT THE LATER STAGE

The object of research is oil fields at a late stage of their development. The most problematic issues in the development of oil fields are the formation and withdrawal of residual oil reserves. This problem is especially acute at the late or final stage, when the oil productivity of the wells decreases and the water cut of the production catastrophically increases. The most acceptable development system in such conditions is the use of methods for increasing oil recovery and, first of all, by injecting water into the reservoir. At the same time, the problematic issue is the lack of reliable information on the paths of water movement from injection to production wells and the imperfection of methods for aligning the injectivity profile in injection wells and the flow profile in production wells.

In the course of the study, statistically analytical methods were used to analyze the state of development of oil fields at a late stage and industrial approbation of methods for tracing water movement and substantiation of a reagent base to align the paths of water movement and oil inflow.

A set of reagents and technological methods for ensuring the regulation of the process of flooding of oil fields at a late stage of their development have been investigated and developed. It has been proven that a promising direction is the injection of a 0.1 % aqueous solution of the Polycar polymer together with water. This solution first of all penetrates into highly permeable, water-washed, formation intervals, contributing to the leveling of the injectivity profile, reducing the water cut of surrounding production wells and increasing their oil productivity.

Thanks to the research carried out, directions and means of improving the systems of field development at a later stage have been developed by organizing targeted (selective) waterflooding of oil deposits based on high-quality and comprehensive control of the movement of filtration flows in the reservoir. This will ultimately contribute to achieving and maintaining the design value of reservoir pressure, preventing a decrease in the rate of decline in oil production, obtaining the design value of the sweep efficiency by waterflooding, and withdrawing residual oil reserves.

Keywords: *structure of residual oil reserves, waterflooding of oil deposits, indicator studies, alignment of the injection profile.*

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1. Introduction

The oil industry in most of the world's oil-producing countries has passed a period of maximum production, which inevitably begins to decline. The maximum level of oil production (13.3 million tons, 1972) was ensured by the introduction into development of a number of large fields. Their role has remained unchanged even now, when about 20 % of fields provide 80 % of oil production, and the remaining 80 % – only 20 % of production. Attempts to reduce the rate of decline in production by increasing the volume of production drilling, as well as identifying previously missed intervals and layers, were of an episodic nature and, for various reasons, could not change the general trend of decline in oil production for a more or less significant period.

The main reason for the decline in oil production in the world is the natural transition of most of the main fields in terms of production and reserves to the late stage of development, which is characterized by their significant depletion. On the other hand, the time of discovery of large deposits, due to which the increase in reserves was ensured, has passed, and geological exploration works are opening mainly very small, small and medium deposits at depths of 4.5–6 thousand meters. Therefore, the increments in proven reserves do not even compensate for the current oil production.

Typical depletion of fields is accompanied by an increase in water cut to 80–85 % and more [1]. So, for example, with an average value of water cut of more than 90 %, 14 fields of the main oil-producing company of Ukraine, OJSC Ukrnafta, are being developed. The average value of the recovery factor reached about 30 % according to the design – 36.5 %, while the world level for the corresponding development modes is 40–50 %. Therefore, the main direction of increasing the levels of hydrocarbon production and achieving high values of the final coefficients of their extraction is a large-scale improvement of existing systems for the development of oil and gas fields using modern science-intensive technologies [2].

The main oil fields are developed by the waterflooding method [3], which today is the most affordable and efficient. At the same time, due to the complex geological structure, large filtration inhomogeneity, dissection and discontinuity of reservoirs, the transition of fields to the final stage of development, the efficiency of waterflooding at the present stage is becoming low.

Direct flow measurements show that the field (deposit) is «cut» by injection water into separate blocks, areas, causing the formation of low-permeable layers not covered by extrusion and undrained zones. According to the results of numerous studies, it has been established that about two-thirds of the residual oil is formed due to incomplete coverage of the reservoir by development, and the rest contain capillary and surface forces in the pore space.

So, the insufficient efficiency of oil recovery at the late stage of field development is in most cases dependent on the imperfection of waterflooding systems. In such conditions, the best way to accelerate the withdrawal of residual oil reserves is the orderly introduction of methods to increase oil recovery based on the identified and plugging of the washed zones (channels) of the formation. One of the directions for the implementation of the task is the use of indicator studies of the paths of water movement in the reservoir and, if necessary, plugging the most penetrating ones.

The relevance of the work is due to the need to generalize the existing state of field development at a late stage and provide acceptable proposals for its improvement and ensure the most complete recovery of residual oil reserves.

Thus, *the object of research* is oil fields at a late stage of their development. *The aim of research* is to improve the systems for the development of oil fields at a later stage in terms of ensuring the most complete recovery of residual oil reserves.

2. Methods of research

The research used scientific methods:
– statistical and analytical analysis of the current state of oil-producing technologies and methods of increasing efficiency in terms of the output of residual oil;
– industrial approbation of the water movement tracing method and substantiation of the reagent base for leveling the water movement paths and oil inflow.

3. Research results and discussion

The priority direction of ensuring the stability of any country in the world, especially at the present stage, is the oil and gas production sector, which forms the country's energy landscape, the economic orientation of its state policy, and reduces dependence on imported energy resources. In this aspect, the raw material base of hydrocarbons and the efficiency of its implementation is and will remain a significant potential for technical progress and economic security.

For example, the oil industry of Ukraine passed the peak of the maximum oil production in 1972, at which its monotonous decline naturally began (Fig. 1).

As for Ukraine, its extreme production in 1970–1973 was ensured by the development of large reserves of deposits, such as Dolynske, Kachanivske, Leliakovske, Glinsko-Rozbyshevske, Gnidyntsivske [4].

The oil industry of all countries of the world, including Ukraine, is characterized by a steady depletion of oil resources, which occurs in the absence of economically and technologically acceptable alternative energy sources [1].

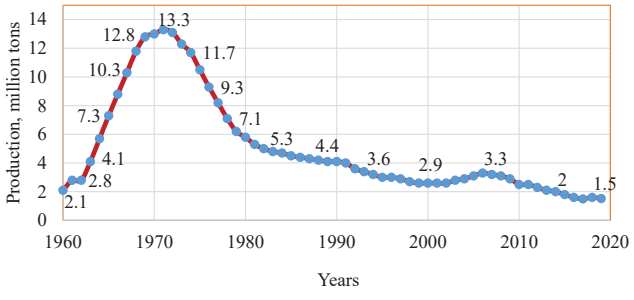

Fig. 1. Profile of oil production on the example of Ukraine

The prospect of discovering significant new oil fields in terms of a high degree of exploration of the subsoil is extremely insignificant. Recently, there have been only small deposits at depths of more than 5000 m. At the same time, residual oil reserves at the fields under development are still quite significant. An episodic increase in production in 2003–2006 (Fig. 1) occurred due to a detailed reinterpretation of geophysical studies, identification and involvement in the development of previously missed naphthonic layers.

The production profile (Fig. 1) is representative for any oil field and is characterized by the presence of four stages [5]:

– I (1960–1968) – intensive development of the field and an increasing level of production (systematic drilling of the field, commissioning of the first-priority project well stock);
– II (1969–1975) – the maximum production level (achieving the highest annual production due to the first-priority commissioning of high-production wells, the introduction of a set of geological and technical measures to regulate the development process);
– III (1976–1985) – declining production (a noticeable decrease in the level of annual production and the rate of oil withdrawal, an increasing water cut in wells, a gradual decrease in the operating stock and a gradual transfer of wells to artificial lift methods, continued drilling of the field);
– IV (1986-present) – late or final stage of development (a significant decrease in production volumes at low rates of withdrawal and high water cut of production, a decrease in the operating stock, systematic repair and restoration, intensifying and water-proofing works).

The duration of the fourth stage is determined by the line of economic profitability, in fact, the minimum flow rate, at which the operation of the wells becomes unprofitable. During the first three stages, 80–90 % of the producing (active) oil reserves are withdrawn from the field.

The decline in oil production in Ukraine could be partially offset by an increase in the number of wells, as is done, for example, in the United States. However, due to objective and subjective reasons, the volumes of production drilling of oil in Ukraine have practically leveled off.

So, most of the fields in Ukraine are at a late stage of development, which is characterized by the accumulation of so-called residual (non-produced) oil reserves in the reservoir. The formation of these reserves is due to the macro non-homogeneous reservoirs and low or «zero» filtration rate in low-permeability zones, layers and lenses

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against the background of an irreversible decrease in reservoir energy, reservoir pressure itself [6].

Residual oil (Fig. 2), due to the high macro-inhomogeneity of the reservoirs and the presence of stagnant zones, is the main reserve for increasing the recovery factor and increasing oil production.

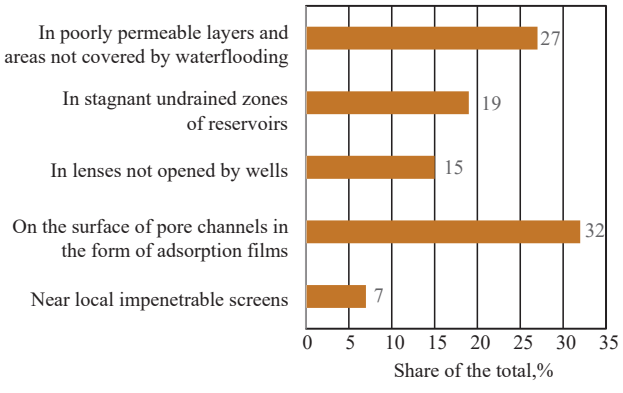

Fig. 2. Distribution of residual oil in the pore space

It is possible to increase oil recovery of the reservoir due to this share of oil reserves by improving existing systems and technologies for field development. First of all, with the use of various methods of targeted impact on productive formations in order to activate the process of hydrocarbon extraction and reduce the amount of residual reserves [7].

In world practice, an impressive arsenal of various methods of impact on productive strata has been developed and tested: hydrodynamic, physical, chemical, physicochemical, thermal, gas, water and gas, microbiological, etc. [8]. However, the most common is the hydrodynamic method of stimulation by waterflooding, which is the basic technology for the development of oil deposits and an effective way to compensate for the formation energy and displace oil from the reservoir. The hydrodynamic method of action by means of water-gas repression is also promising for the extraction of retrograde condensate from the reservoir [9].

Waterflood development systems provide the greatest effect in the development of deposits with relatively low oil viscosity, high porosity and reservoir permeability [10].

Waterflooding is the main method for developing oil fields in Ukraine, the widespread use of which has made it possible to maintain high levels of annual oil production for a long time. For example, about 30 % of oil fields in Ukraine are developed using waterflooding [10].

The architecture of the waterflooding process is based on achieving the design values of the reservoir drainage coefficients, its coverage by waterflooding and oil squeezing out with water. The drainage factor determines the fraction of the naphthonic volume, in which the movement of fluids takes place, the sweep factor determines the fraction of the volume of the drained naphthonic reservoir, and the displacement factor – the degree of replacement of oil by water in the porous medium. These coefficients determine the success of waterflooding, and their product is the oil recovery coefficient. Loss of control and management of these indicators can lead to premature water breakthrough in production wells and deterioration of the efficiency of reservoir development as a whole (Fig. 3).

The waterflooding method is implemented both as conventional stationary water injection into the reservoir, and non-stationary (cyclic, change in injection pressure, change in injection volumes, change in the purpose of production and injection wells). But in any case, the process requires careful geological and industrial control by the nature of water flow into the reservoir, its movement and exit to the surface through production wells [10].

One of the directions of such control is the indication of the paths and directions of water movement from injection to production wells using marker substances – tracers.

This method makes it possible to:

– determine the true speed and direction of water movement in the formation;

– degree of hydrodynamic connection between wells and layers;

– efficiency of the process of pushing oil out by water and the influence of the operating modes of individual wells on it;

– to assess the degree of reservoir anisotropy.

It is possible to obtain such information without violating the established operating mode of the oil producing company only with the help of tracers, which are reliably identified in conditions of their insignificant amount in water and are injected into the reservoir. The procedure for tracing filtration flows consists in supplying an indicator solution to the water flow and systematically taking fluid samples from surrounding production wells to determine the presence and concentration of the indicator in their products. On the basis of tracer studies, the modes of injection and withdrawal of fluid in the corresponding wells are corrected.

Chemical elements, salts of chemical compounds, dyes (fluorescyl, methylene, uranyl), stable radicals, isotopes, etc. are used as indicators. To differentiate the effect of several injection wells on the same production wells, polyindicator methods are used by injection of different indicators.

For example, in recent years, nitrogenous compounds have been used in Ukrainian deposits [11] – nitrates (ammonium nitrate NH_4HO_3) and carbamide (urea H_2HCONH_2 and thiourea H_2NSCHH_2), Fig. 4.

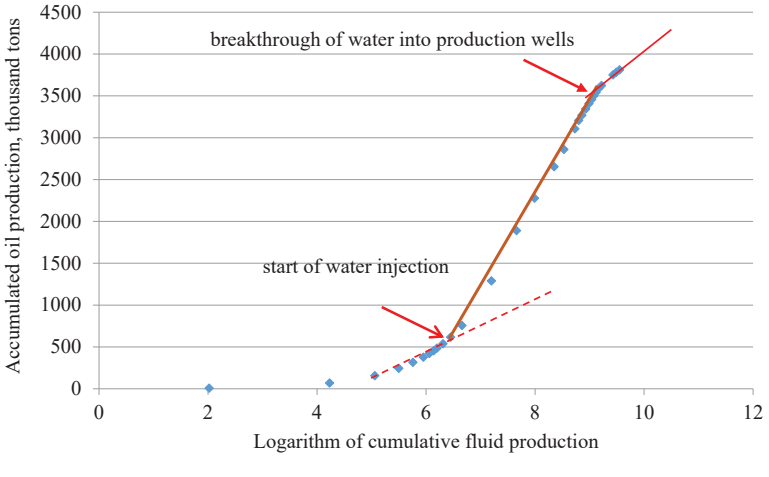

Fig. 3. Characteristics of oil squeezing out during flooding of the B-22 horizon of the Bugruvativske field

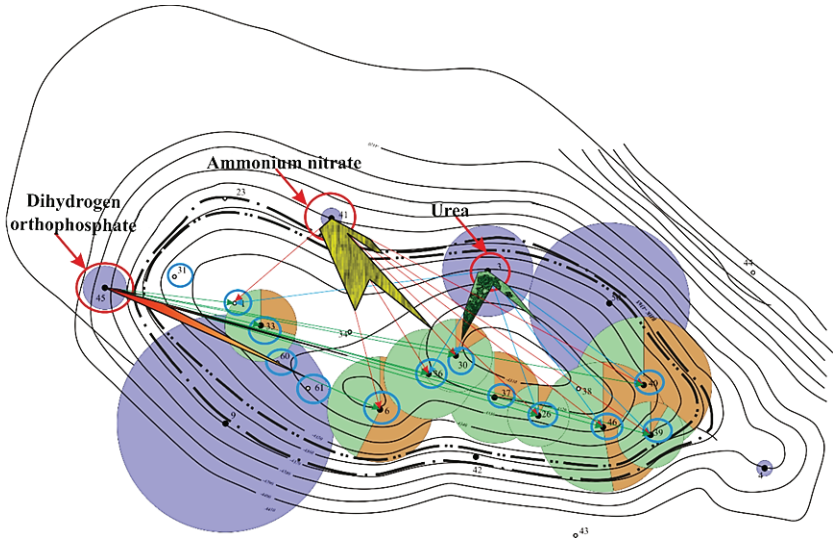

Fig. 4. Fragment of indication of the B-19 horizon of the Perekopovske oil field through injection wells No. 3, 41, 45

The use of indicators at the Bugruvativse, Anastasivse, Perekopovske, Koziivske, Chizhevske, Bogdanivske, Malodivytske, Skorokhodivske, Dolynske, Severo-Dolynske and Spaske deposits will allow to:

– identify promising areas for drilling priority wells;
– optimize the work of the injection fund to eliminate local water breakthroughs;
– determine partially blocked areas of the bottomhole formation zone;
– recognize superior filtration directions;
– build a strategy for leveling the profile of injectivity in injection wells and inflow in production wells.

A promising direction is the injection together with water of a 0.1 % aqueous solution of polymer «Polycar», which, first of all, penetrates into highly permeable, water-washed, reservoir intervals, contributing to the leveling of the injectivity profile, reducing the water cut of surrounding production wells and increasing their oil productivity.

The physicochemical properties of the polymer consist in thickening, or increasing the viscosity of water and, thereby, decreasing the ratio of oil viscosity and squeezing out fluids and affecting the phase permeability of the reservoir system [12].

Gasified thick oil, hydrophilic oil emulsions, oil-and-oil mixtures, 8–10 % solution of hydrolyzed polyacrylonitrile mixed with calcium chloride, 0.5 % solution of caustic soda, hydrolyzed polyacrylonitrile formalin mixtures are also used as streams of hydrochloric materials [13]. For reservoirs with natural or artificially created fractures in the formation, dispersed or granular materials are used [14].

The therapy of the action of such reagents on the formation consists in the fact that they first of all fill the most permeable intervals (intervals) of the formation, reducing their permeability, and, consequently, the permeability, causing a redistribution of filtration flows or leveling the profile of water entering the formation.

An acceptable method for improving the system of oil field development at a later stage is to change the directions of filtration flows, which is implemented by systematically stopping injection wells, or changing their mode of operation (injection pressure, fluid flow rate).

4. Conclusions

Thus, as a result of the analysis of the directions for improving oil field development systems, it was proved that the implementation of targeted waterflooding of oil deposits at a late stage of field development in conjunction with high-quality and comprehensive control is aimed at:

– achievement and maintenance of the design value of reservoir pressure;
– prevention of a decrease in the rate of decline in oil production;
– increasing the efficiency of geological and technical measures in production wells;
– ensuring the design value of the reservoir sweep efficiency;
– accelerating the rate of extraction of residual oil reserves.

For example, it is economically and technologically justified to involve 100–150 million tons of oil from the current residual reserves in the development of Ukrainian fields, which is equivalent to achieving the final oil recovery factor of 46–51 %, corresponding to the level of modern world development systems [14].

To ensure the implementation of these scenarios, it is necessary to solve a number of priority technological and organizational problems. As part of technological tasks, first of all, it should be highlighted:

– deployment of extensive industrial and scientific research to localize residual oil;
– introduction of modern methods of oil recovery;
– optimization of the production wells network;
– drilling of wells of complex architecture, including wells, with horizontal boreholes;
– high-quality primary and secondary opening of productive formations;
– use of streams of hygienic technologies, directed methods of intensifying production and limiting the inflow of formation waters, and the like.

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