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Article

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SELECTION OF EFFECTIVE METHODS OF INCREASING OIL RECOVERY IN DEALED FIELDS BASED ON RETROSPECTIVE ANALYSIS

The object of research is methods of increasing oil recovery in «old», depleted oilfields. One of the main tasks of the oil-extracting industry in any country in the world was and still is ensuring the project level of oil production at the maximum possible coefficient of its extraction from the subsoil. In this case it is extremely important to study and use technological methods and means of acquired experience in oilfield development.

The paper considers the historical aspects of the development of stabilization and oil recovery methods from 1770s to the present day on the example of Ukrainian oilfields. In parallel with the history of the implementation of methods, their physical and technological content and conditions of application are discussed. Of all the methods used to increase the level of oil production, the most effective ones, which have found application at certain stages of the Ukrainian oilfields' development, are considered. This is, first of all, a vacuum process, areal flooding, cyclic flooding, gas and water-gas repression, injection of surfactants, surfactant polymer-containing systems, polymer flooding, horizontal branched drilling. The methods development analysis is considered against the background of their geological and industrial acceptability and obtaining technical and economic effects. Based on the results of the study, a group of methods has been identified. These methods are advised to apply in geological and industrial conditions, similar to those described, which should ensure the expected efficiency. Undoubtedly, along with this, it is advisable to use the methods of mathematical modeling of oilfield development processes. Proposals are formulated on the conditions and principles of applying the methods under consideration in order to improve the systems for the development of oilfields. It has been established that the most acceptable methods of increasing oil recovery in depleted oilfields are the injection of surfactant solutions both independently and together with an aqueous solution of polyacrylamide, creation of gas-water repression and polymer flooding, in which preference is given to AN132SH and AN125SH reagents of FLOPAAM S series from SNF FlOERGEL.

Keywords: *depleted oilfields, stabilization of the production level, surfactants, polymer systems, additional oil production.*

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1. Introduction

The main problem of the world oil industry is a gradual decrease in oil production levels, as a result of monotonous changes in the thermodynamic state of the reservoir system [1]. This, in turn, necessitates the introduction and continuous improvement of the appropriate methods of active influence [2] on the reservoir system, which tends to constantly change in time and space of the oil-saturated reservoir.

Consequently, regardless of the stage of development of any oil field, one of the cardinal directions of increasing and stabilizing the level of production is the formation of an arsenal of the most acceptable methods of influencing the reservoir system with their constant targeted improvement.

In this aspect, an important role is played by the study and analysis of the existing experience in the development and development of «old» deposits on the example of Ukrainian deposits. The «old» oil fields of America (Pennsylvania) [3], Azerbaijan («Oil Rocks») [4], Russia (Krasnodar Territory) [5] have a similar history. Such deposits are still in development, which undoubtedly ensures the relevance and expediency of the presented study.

Thus, *the object of research* is the methods of increasing oil recovery in «old», depleted fields. *The aim of research* is to assess the prospects for the use of various methods of increasing oil recovery in depleted fields in the modern realities of the oil industry on the example of Ukraine.

2. Methods of research

The research carried out was based on standard methods of statistical and analytical analysis. Technological characteristics were determined based on the results of experimental laboratory and industrial research.

3. Research results and discussion

An integral part of the history of the development of the world oil industry is the formation and development of oil fields in the Carpathian region of Ukraine. The first in Ukraine is the Sloboda-Rungursky field (now Kolomyia district of Ivano-Frankivsk region), commercial oil production in which began in 1771. First, oil was extracted from pits-wells and mines, and then from drilled wells, first by hand, and then by percussion method. It was here that new technologies for production and impact on oil reservoirs were born and applied [6–8].

In the Boryslav region [9–11], commercial oil production began in the village of Nahuevychi from the first well dug for this purpose. In 1862, the first well was drilled by percussion in the Boryslav oil-field region, and in 1907 the mechanized method of oil production by pistoning or swabbing was introduced. This method of well operation was dominant in Boryslav during 1907–1947. The use of swabbing as a method of operating wells contributed to a significant increase in production from wells that stopped flowing. The extremely high technological efficiency of this method of well operation is evidenced by the fact that oil production increased from 1003.3 thousand tons in 1907 to 1965.2 thousand tons in 1909. At that time Boryslav, as part of Galicia, was the third largest oil producer in the world after the USA and Russia. However, uncontrolled swabbing contributed to the rapid depletion of the subsoil. The swabbing method created high drawdowns on the formations, which is especially detrimental for the deposits developed in the dissolved gas mode.

In 1921–1971, at the Skhodnytske field, they began to use the vacuum process, due to which they additionally obtained 74 thousand tons of oil. In 1927, this method began to be applied at the Boryslav field.

Having exhausted the possibilities of developing fields in depletion mode, in order to increase oil recovery in 1931, gas repression was introduced at the Skhidnitskoye field using oil and natural gas. The most widespread and prolonged was the air repression, which lasted until 1970. The introduction of this technology made it possible to additionally produce 310 thousand tons of oil over 40 years, for which 620 million m3 of oil and natural gas were pumped into the Yamnenskaya deposit. Attempts to introduce gas repression at the Boryslav field were made in 1936, but the process acquired industrial significance only in 1947, when gas was injected into the most depleted «Boryslav sandstone», and then (1956) – air. Thanks to the introduction, up to 149 thousand tons of oil per year were obtained, which amounted to 45.7 % of the total production of the Boryslav oil field region.

In August 1954, areal flooding of the Yamnensky sediments of the MEP (Miriam-Equivalent-Polminy) section of the Boryslav oil field began by injecting 50 m^3 of fresh water at a pressure of 2 MPa into well No. 1138 every day. It is suffice it to say that this area was a testing ground for oil production intensification methods. Here, 28 old wells were deepened, areal flooding, new wells drilling, electric heating, injection of high-pressure steam into the reservoir were introduced.

In 1957–1958, for the first time in the practice of oilfield business, four shallow (up to 500 m) horizontally branched wells (No. 1543, 1544, 1545 1546) were drilled, the oil flow rates in which were 3–5 times higher than in the surrounding vertical wells.

Most of the field experiments to stabilize oil production in the Boryslav region were carried out at old fields. One of these was the injection of high-pressure steam in the MEP areas of the Boryslav field using the Japanese Takuma steam generator. The same experiment was carried out at the Miriam site of the Boryslav field, but with the help of the UPGG-9/120 steam generator made in the USSR. All of these activities have proven to be effective.

The main object of development of the Bytkov field (Ivano-Frankovsk region) is the menilite deposits of the «Glybynna» fold, the commercial development of which began in 1957 [8, 12]. In the initial period, with a small number of wells, the reservoir was developed in elastic mode. Later, with a sharp increase in drilling and oil production, the dissolved gas regime began to develop in the deposits, which led to an increase in gas factors, and starting from 1963 – to a decrease in oil production.

In order to increase oil recovery in 1958–1961, experimental work was carried out to maintain reservoir pressure by injecting water into the reservoir [13].

9 wells were used for water injection. Their low injectivity (10–40 m^3/day) did not allow recommending this method for widespread implementation. The discovery in 1958 of an oil-saturated reservoir in Eocene sediments with pressures that were 10 MPa higher than the current reservoir, allowed for the first time in the former USSR to introduce gas repression by natural bypassing gas from a gas condensate reservoir to an overlying oil reservoir.

In 1968, due to the equalization of reservoir pressures in gas condensate and oil deposits, natural gas bypass was stopped. For the period 1962–1968, 1.9 billion m^3 of gas was pumped into the oil reservoir, which compensated for the withdrawal of fluid in reservoir conditions from the beginning of development by 32 %, although in certain periods (1965–1974) the annual compensation varied from 76.5 to 64.2 %. Due to such a bypass, an additional 980 thousand tons of oil were produced.

Taking into account the positive result of maintaining reservoir pressure by gas injection, a compressor station was built in 1971 and high-pressure gas injection into productive strata began. The resumption of gas injection had a positive impact on the development status of the reservoir. An increase in well production rates and stabilization of gas factors were noted. However, in spite of the positive result of the gas repression process, there were premature gas breakthroughs in the production wells in the field, which were located near the injection wells.

To combat gas breakthroughs, gas injection was continued in the cyclic injection mode. However, this did not lead to the achievement of high efficiency of the process in conditions when the reservoir pressure in the reservoir decreased to the bubble point pressure. The Central Research Laboratory (CRL) of Ukrnafta (now the Research and Design Institute of Ukrnafta) proposed to maintain reservoir pressure by cyclic water and gas injection. This method was approved in 1972 as an industrial experiment, and in 1977 it was already introduced on a large scale as a way to maintain reservoir pressure by creating gas-water repression.

Starting in 1986, the volumes of gas and water injection began to decline and in 1994 gas injection were stopped, and due to the depletion of water sources, water injection was also stopped.

Since 1994, only produced and produced water has been pumped into the reservoir, small volumes of which did not significantly affect the state of development of the reservoir.

The method of creating water-gas repression using gas dissolved in oil (associated gas) has passed laboratory testing. The results of experimental work carried out at the Central Scientific Research Laboratory of «Ukrnafta» are shown in Fig. 1.

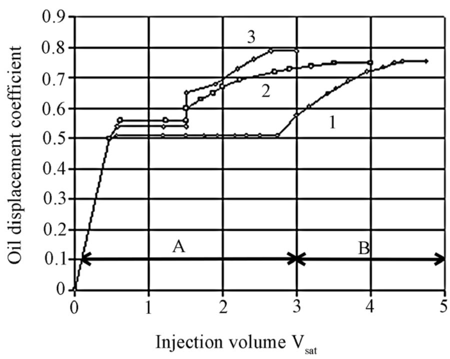

Fig. 1. Change in the displacement coefficient of oil during its degassing (P=0.25P_{sat}) followed by water injection: 1 – pressure change at a closed outlet from the reservoir model and water injection without pressure reduction (section A); subsequent pressure reduction with an open outlet from the reservoir model and water injection (section B); 2 – simultaneous water injection and pressure reduction; 3 – pressure reduction followed by water injection

In all experiments, at the first stage, waterflooding was simulated in the volume of 1.5 pore space volumes until the cessation of oil flow from the reservoir model. At the next stage, the pressure in the reservoir model was reduced to a value of 0.25 of the oil saturation pressure (0.25P_{sat}).

Curve 1 illustrates the results of an experiment in which the pressure in the reservoir model was reduced to 0.25P_{sat} without displacing fluid from the model. After 24-hour holding of the system for oil degassing, water was injected into the reservoir model (section A).

Section B shows the subsequent decrease in pressure at the exit from the reservoir model and water injection, where an increase in the oil displacement coefficient is already noted.

Curves 2 and 3 display the research results by reducing the pressure without pumping water (curve 3) and with the simultaneous injection of water and decreasing the pressure (curve 2).

The research results show that the higher the saturation pressure of oil with gas and the greater the presence of gas dissolved in oil, the higher the process efficiency will be.

In 1976 at the Strutynske, and in 1979 – at the Staryi Sambir fields, in order to increase oil recovery, the injection of solutions of surfactants of low concentration was introduced [14]. Oil production from the Menilite reservoir of the Strutynske field began in 1962 in the natural regime (first – elastic, and then – in the regime of dissolved gas), which caused a decrease in reservoir pressure below the saturation pressure of oil with gas. Therefore, since December 1966, the field has been flooded with a boundary, and since 1973 – with an in-circuit flooding. In order to increase the completeness of oil recovery, in February 1976, the injection of aqueous surfactant solutions was started at the field.

Laboratory studies and hydrodynamic calculations have shown that the injection of aqueous surfactant solutions at a relatively late stage of the development of the Strutynske field will provide an increase in the final oil recovery by 2.3 %. To do this, it was necessary to inject such a volume of surfactant solutions into the productive formations, which would ensure the creation of 40 % of the rim from the volume of oil-saturated pores of the formation.

By the beginning of the injection of aqueous surfactant solutions, 3.2 million m^3 of water were injected into the productive strata and 53.2 % of the initial recoverable oil reserves were withdrawn. The oil recovery factor reached 0.17, the water cut was 23 %. The injection of aqueous surfactant solutions was carried out during 1976–1991. During this period, 4.55 million m^3 of an aqueous surfactant solution was injected into the reservoir, which ensured the creation of a 30 % rim of the volume of oil-saturated pores in the reservoir. Surfactant injection ensured an increase in the final oil recovery by 2.1 %, which amounted to 189.6 thousand tons of additional oil produced. Analysis of the actual field development indicators showed that the injection of aqueous surfactant solutions contributed to an increase in the sweep efficiency from 0.54 (during water injection) to 0.66 (during the injection of aqueous surfactant solutions).

The development of the Yamnenskaya reservoir of the Staryi Sambir field began in 1969. In 1976, a boundary waterflooding was introduced here, and since 1979 – the injection of aqueous surfactant solutions, which consisted of a mixture of anionic (sulfonol) with nonionic (prevocel, and then OP-10, neonol) in a ratio of 1:1 and a concentration of 0.05 %. Such a mixture of reagents, as well as their ratio, was recommended on the basis of research carried out in the Central Scientific Research Laboratory of «Ukrnafta». It has been proved that the coefficient of oil displacement by aqueous solutions of a mixture of surfactants from core samples of reservoir rocks of the Carpathian region is higher than during conventional waterflooding.

The surfactant mixture has a high surface activity, that is, it provides a lower interfacial tension (for the conditions of the Staryi Sambir field, about 0.05–0.08 mN/m). The created fringe in the amount of 0.152 of the volume of oil-saturated pores was pushed along the reservoir by water. The introduction of this technology made it possible to additionally produce 92.4 thousand tons of oil. In 1999, with the achieved oil recovery factor of 0.173 and water cut of 11 % at the Staryi Sambir field, cyclic water injection began, which, based on the experience of developing other fields in the Carpathian region (Dolinske, Severo-Dolinske), significantly improved the state of its development.

For the Dovbushansko-Bystrytske field, it is recommended to pump surfactant solutions together with polyacrylamide (PAA). Such solutions are called surfactant polymer-containing systems (SPCS). SPCS consists of 0.05 % surfactant (a mixture of pinol and savenol in a 1:1 ratio) and a polymer of 0.03 % concentration. The project provides for the creation of a SPCS rim in a volume equal to half the volume of the drained pore space or 184 thousand m^3, which is subsequently pushed by water.

At the pilot site of the field, the injection of SPCS was carried out through well No. 70, and oil production was carried out by wells No. 4, 9, 88, 93 and 128 (Figs. 2, 3). For 3 years of implementation, an additional 940 tons of oil were produced, which significantly exceeded the design value of 470 tons.

The SPCS injection was the first field experiment in Ukraine that uses polymers to enhance oil recovery and can be applied to other fields as well. And although the semantic load of using polymers in this experiment is somewhat different than simply increasing the viscosity of the injected water, this experience shows that polymer flooding can take place in the development of similar fields.

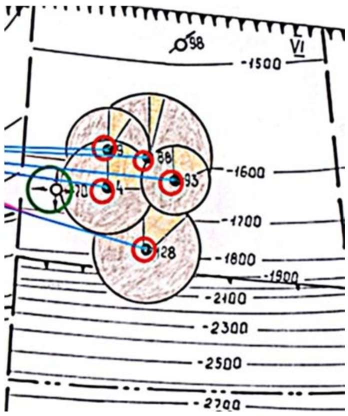

Fig. 2. Fragment of the development map of the pilot site of the Dovbushansko-Bystrytske field

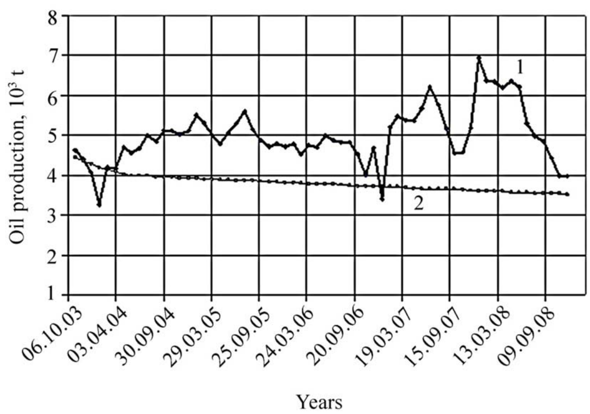

Fig. 3. Dynamics of total oil production at the pilot site of the Dovbushansko-Bystrytske field: line 1 – actual oil production; line 2 – predicted oil production without injection of SPCS solutions; → – start of injection of SPCS solutions

A further development of these studies was also a set of experimental studies carried out at the Central Scientific Research Laboratory of Ukrnafta, aimed at testing the polymer flooding method in the experimental section of the B-16 horizon of the Bugruvatovske field with high-viscosity oil [15].

The average depth of the V-16 productive horizon is 3306 m, the reservoir temperature is 93 °C, the oil viscosity in reservoir conditions is 20 mPa·s, and the total salinity of the reservoir water is 175 mg/dm^3.

Due to the high temperature and salinity of the formation water, the search for the optimal type of polymer from SNF FlOERGEL (France) was carried out. About 20 grades of acrylamide copolymers of various types (non-ionic, ionic, anion-active, cation-active) have been investigated.

It was found that standard hydrolyzed polyacrylamides of the FLOPAAM S series with a molecular weight of 8 to 22 million daltons and a degree of hydrolysis of 20–30 mol. % have better properties in terms of thickening of formation water.

Thus, for a 0.05 % solution of polymers 3630 S, 3530 S, 3430 S, 3330 S, the dynamic viscosity at a shear rate of 61.2 s^{-1} varies in the range of 2.0–2.35 mPa·s. Polymers of the same series 2530 S, 2430 S, 2330 S with a lower degree of hydrolysis have somewhat lower thickening properties. The dynamic viscosity changes in the range 1.6–1.9 mPa·s at a shear rate of 61.2 s^{-1}. Based on the studies carried out, a project was drawn up for the development of the B-16 horizon of the Bugruvatovske field using polymer flooding.

The analysis carried out allows the developers of oil fields to obtain information on the feasibility of using methods to increase productivity in «old» fields.

4. Conclusions

The most effective and acceptable methods of increasing the final oil recovery in «old» and depleted fields, depending on the acceptable geological and production conditions, are:

– injection of surfactant solutions (preferably in conjunction with PAA) and the creation of gas-water repression in the reservoir after the formation of free gas in the reservoir due to its release from oil;

– polymer flooding using AN132SH and AN125SH reagents of the FLOPAAM S series from SNF FlOERGEL, which provides an 8 % increase in oil displacement efficiency compared to using the traditional flooding method.

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