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Flow Diversion Technologies and Water Restriction

Bulchaev N.D.
Institute of Oil and Gas
Grozny State Oil Technical University named after acad. M.D. Millionshchikov,
Grozny, Russia
nbulchaev@yandex.ru

Mintsaev M.Sh.
Grozny State Oil Technical University named after acad. M.D. Millionshchikov,
Grozny, Russia
ibragim.ggni@mail.ru

Gairabekov I.G.
Faculty of Civil Engineering
Grozny State Oil Technical University named after acad. M.D. Millionshchikov, Grozny, Russia,
Kh. Ibragimov Complex Institute of the Russian Academy of Sciences,
Grozny, Russia
haladov_a_sh@mail.ru

Khaladov A.Sh.
Institute of Oil and Gas
Grozny State Oil Technical University named after acad. M.D. Millionshchikov,
Grozny, Russia
rusl.molaev@ yandex.ru

***Abstract* – Changing the direction of flow in a porous medium, in reservoir conditions, is important for increasing the flow of oil to the bottom of the well. The use of flow diverting technologies contributes to the alignment of the injectivity profile of injection wells and the selection profile in producing wells. Due to the heterogeneity of reservoirs in permeability and other properties of rocks, fluid flows have different speeds of movement and filtration. The resulting gradients of speeds and pressures lead to the destruction of rocks and the removal of solid particles along with oil. Very often for various reasons, depressurization of casing strings and watering of wells occur. In work methods of isolation of water inflows with the help of various plugging structures are considered. Among the insulating materials proposed development "Ufanipineft", which have passed industrial tests and showed high success. Many formulations are zoned for the oil-producing regions of Russia and foreign countries.This article discusses current issues of the use of flow-diverting technologies and the isolation of water inflows for the intensification of oil production and the repair and insulation works. The presented insulating and plugging compositions were developed by domestic research and design organizations and zoned in many oil and gas producing regions of Russia. At the same time, in order to ensure high success of the application of new developments and the efficient operation of oil companies, additional research and testing of the proposed new products in specific mining and geological conditions have to be conducted. These technologies are very relevant for the conditions of the Chechen Republic.**

Keywords* – *flow rejection; isolation of water; clay content; productive formations; heterogeneous reservoir; zoning compositions.

I. Introduction

Permeability reservoir heterogeneity is one of the main reasons for the uneven displacement of oil by water and the premature watering of highly permeable interlayers with incomplete reservoir formation, and in the late stage of field development - the formation of extensive flushed zones in the reservoir. In conditions of high clay content of productive formation, especially of their cementing materials, water ingress into them leads to swelling of the clay component and weakening of adhesion forces between the formation grains. That is why the role of flow diverting technologies in enhancing oil recovery and preventing the removal of mechanical impurities is quite high.

The use of flow diverting technologies contributes to leveling the injectivity profile of injection wells, redistributing filtration flows in highly permeable reservoirs of highly watered streams of productive formations and eliminating water breakthroughs by increasing the seepage resistance of watered areas of the formation. Blocking highly permeable formation intervals is possible based on the use of a wide range of reagents: sediment-forming, polymer and foam systems, water repellents, crumb rubber.

II. Main part

The use of a fibrous-dispersed system (FDS) to align the permeability heterogeneity of the reservoir by increasing the filtration resistance of water-washed high-permeability intervals based on the use of two dispersed materials: wood flour and clay powder [1]. The main component responsible for the manifestation of the effect of redistribution of existing filtration flows is wood flour, which is a product of dry grinding (milling) of wood. Depending on the brand, it contains particles with a diameter of from several to hundreds of microns. They have a highly developed surface and porosity formed by the interstitial voids of spaces. On their surface are the finest fibrous branches (fibrils), which give wood flour the ability to structure itself with other dispersed particles due to the forces of physical interaction. Due to the large amount of intervolume spaces (voids) that are vigorously absorbing water, wood flour is capable of swelling, mainly internal and develops significant pressure of swelling, showing a wedging effect, which is especially important in porous mediums.

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Due to these properties, wood flour in the pore space of water-washed zones of the formation in contact with clay or the surface of the rock pores forms a fibrous-dispersed structured system that can significantly increase the filtration resistance of highly permeable reservoir intervals.

Polymerdisperse systems (PDS). The principle of action of the PDS is based on increasing the filtration resistance of watered zones of the formation of the resulting mineral complex [1, 2].

To improve the functioning of the PDS in various geological conditions, increase their displacing properties, control the rheological properties, increase the formation coverage with water flooding, modified systems were developed with the introduction of additional reagents: PDS-PAV, PDS with calcium chloride, PDS with sodium carbonate, PDS-SLA (stabilized lean adsorbent), PDS-aluminum chloride, etc.

A similar technology based on modified polymer-dispersed systems was developed by employees of the PPF "Idzhat" [3]. The polymer solution moving in front of the suspension modifies the surface of the porous medium due to adsorption and mechanical retention of polyacrylamide (PAA) macromolecules, thereby reducing the concentration of the solution. Particles of clay or other rocks entering the reservoir in the form of a suspension, interact with the macromolecules of the polymer - adsorbed on the rocks and being in suspension. The first factor, on the one hand, reduces the penetration into small pores, on the other - leads to a strong retention of dispersed particles, and the second factor contributes to flocculation. The presence of free segments of macromolecules after primary adsorption provides a strong connection of dispersed particles, the resulting polymer dispersed aggregates with the surface of rocks, thereby creating a bulk, stable in dynamic flow mass.

Technologies based on water-soluble polycation exchangers are represented by injection of the polymer hypan, WSPC-402.

Reverse emulsions. The technology consists in pumping emulsion composition on the basis of emulsifier through injection wells. Invert emulsions, stabilized by Neftenol NZ and containing formation water, stable gasoline and calcium chloride, contain water as the dispersed phase, and the hydrocarbon solution Neftenol NZ is used as a dispersion medium [1]. Since the external phase of such emulsions is hydrocarbon, these emulsions easily solubilize residual oil, creating a zone with a high oil content at the front of displacement, and transfer it to the producing wells. In addition, by partially plugging the most permeable interlayers, they redistribute injection water flows into low permeability interlayers, involving or increasing their share in the development. In addition, some components of the emulsion composition, adsorbing on the surface of the rock, hydrophobizing it, which reduces the phase permeability of water in the flooded areas of the reservoir, contributing to the redistribution of injected water flow and limiting the flow of water into the producing wells.

In addition to Neftenol, other reagents are used to create inverse emulsions, for example, hydrocarbon solvents and surfactants using the SNPCH-9630 reagent or emulsion.

A certain development of the approach was the technology of forming an invert emulsion based on polysyl-DV of the RITEK company [4].

Organosilicon compounds. To block highly permeable intervals, selective materials based on organosilicon compounds (OSC) are used [1]. In these technologies, a number of organosilicon reagents are used: orthosilicic acid esters (AKOR, product 119-126, 119-296T), oligoorganoethoxy (chlorine) siloxanes (product 119-204), glycol ethers of organosilicon compounds (VTS-1, VTS-2) , polyethylsiloxane (product 136-41), metal organosiloxanes, etc., as well as their combination with PAA, carboxymethyl cellulose, hydrochloric acid, chromates of potassium and sodium, surfactant. Organosilicon compounds are capable of forming, in formation conditions, a polyorganosiloxane polymer blocking water-saturated rock, which has high adhesive characteristics to the rock, hydrophobic activity, and high selective properties.

Liquid glass (Na2SiO3). When pumping liquid glass into the formation, insoluble sediment occurs, which reduces the permeability of the highly permeable zones of the formation [1]. To ensure the possibility of injection into the formation of the planned volume of insulating composition in front of the liquid glass, it is desirable to inject a buffer fluid, which is an aqueous solution of sodium carbonate. Sodium carbonate, forming insoluble compounds with calcium and magnesium ions, removes them from the formation water, as a result of which the liquid glass being pumped behind it reaches in a non-coagulated state a predetermined depth of penetration into the formation. In the process of aging in the formation, liquid glass coagulates in the flooded area due to the diffusion of calcium and magnesium ions from the formation water and clogs the conductive channels. Coagulation of liquid glass does not occur in oil-saturated zones, since there is no source of calcium and magnesium ions. The reasons constraining the more extensive use of liquid glass are the low strength of the resulting gel and the difficulty of processing at negative air temperatures.

Biopolymers. Advances in biotechnology in recent years have provided the appearance on the world market of a group of water-soluble polymers — microbial polysaccharides, whose physicochemical and rheological properties of solutions are not inferior to the properties of polyacrylamide solutions, and their resistance to temperature and shear loads is higher than that of PAA [1].

Recently, a microbial polysaccharide producing strain has been isolated in Russia and its production technology has been developed - exopolysaccharide [5]. A distinctive feature of the domestic biopolymer is the experimentally confirmed possibility of its use in the form of a fermentation liquid, which is of fundamental importance. The elimination of the stages of isolation and drying during the production of a biopolymer provides a multiple cost reduction and allows preserving the useful properties of the solution that are irreversibly lost with traditional methods for isolating dry biopolymer from the post-fermentation liquid. Distinctive features of the biopolymer are low cost, potentially high technological efficiency of application and the absence of resource limitations.

In addition to these flow-diverting technologies, it is possible to use Temposkrin reagent and rubber crumb to block highly permeable intervals.

Reagent "Temposkrin" is a powdered cross-linked polyacrylamide, saline water, an aqueous clay system with clay content of 1.0-30.0% and an aqueous solution of nonionic surfactant [1].

The peculiarity of "Temposcrin" and similar systems is the preliminary treatment of polyacrylamide with γ-irradiation, which leads to the formation of a "net" polymer, characterized by adjustable gel kinetics, uniformity and continuity of the gel, smoothly controlled rheological properties [6].

The essence of the method lies in the fact that a fragmentary cross-linked polyacrylamide is injected into the formation through injection wells and dispersed system (clay suspension) is injected directly into the formation. The novelty of the use of the Temposkrin PGS technology is that it is a combination of two different methods for forming gels: gel synthesis in the formation; pre-receiving the gel, followed by injection into the formation. Due to the dispersed structure of the gel "Temposkrin" consisting of many small gel particles with a size of 0.2 - 4 mm, it has a high mobility and penetration with respect to cracks and large pores. These properties are comparable to those for liquids. However, the gel does not penetrate into low-permeable and hydrophobic areas of the formation; since the sizes of gel and hydrophilic particles are larger than the pore sizes of such rocks. This explains the selective properties of Temposcrin.

Another dispersed system for flow deviation is a composition based on crumb rubber [1]. The advantage is the low cost of the initial reagents, which are waste rubber and oil refining industry. The compositions are applicable in fairly wide temperature boundaries and the environment and the reservoir, as well as in various geological conditions.

One of the options [7] provides for obtaining rubber crumb of 2–15 mm in size from waste rubber of grade 308, 346, 350, etc. Before use, it is mixed with engine waste oils, for example, engine oils of waste (EOW), industrial waste oils (IWO) or a mixture of waste oil (MWO), regulated by GOST 21046-86, and oil. Keeping and mixing this mixture for 1-1.5 days leads to swelling of crumb rubber and its acquisition of elastic properties. Before injection into the formation, the mixture is intensively mixed and then injected into the injection well. The composition is forced into the formation and isolates large water supply channels. In the pores of the formation, an additional swelling of the rubber crumb to the maximum takes place and an elastic ring is formed around the watering zone.

Taking into account the mechanism of formation of water-insulating masses and physico-chemical principles of exposure to the host environment, we can distinguish five groups of chemical reagents and, accordingly, methods based on them: cured, gel-forming, sediment-forming, water-repellent, foam systems [1].

With the isolation of the bottom water and the fromation water itself, so-called foam systems have been widely used [1, 8]. The mechanism of isolation of water in the application of foam systems is as follows:

cleaning the BHZ as a result of dispersing the blocking clayey material, paraffin, asphalt-resinous substances and their further removal during well development due to the solubilizing action (colloidal dissolution) of the formed micelles in the foam system. The main result of this is the introduction to the development of low-permeable interlayers;

blocking the paths of water movement by sticking gas bubbles to the surface of the water conducting channels and forming films of colloid-dispersed compounds;

isolation of highly permeable zones of the formation, which are the main source of watering.

Two- and multi-component foam systems are used. Due to the additional components, the stability of multicomponent foam systems is 15 to 60 times higher than for two-phase foam.

The area of effective application of foam systems is: low and medium formation pressure, unlimited well water cut, pronounced heterogeneity of interlayers, the presence of a mudcake on the walls of a well, the presence of clay cement in terrigenous rocks. Certain disadvantages include: the complexity of the preparation and injection of the composition due to its complexity with the injection in the winter.

The composition of the AKOR is a grouting material designed to limit the breakthrough of the bottom water, the flow of water from water-saturated formation located close to the productive zone, and the elimination of ring circulation. It was developed at VNIIKRneft and has been widely used in waterproofing works from 1986 to the present. Currently, AKOR-BN materials are single-pack, silicone insulation materials intended for carrying out waterproofing works in production wells in difficult climatic conditions (temperatures up to -50 °C). Higher diphilicity of AKOR compositions gives them selectivity, which was confirmed when testing compositions on model formations.

The composition is widely used in the fields of Western Siberia.

In the method of restricting the flow of water into the production wells using an oil-sour mixture, three principles are used to form a water insulating mass [1]

1) interacting with carbonate components of rocks and salts of formation water, sulfuric acid forms a precipitate - poorly soluble gypsum;

2) in the presence of sulfuric acid, polymerization and polycondensation of asphaltenes and resins contained in oil occur with the formation of acid tar;

3) at high temperatures, acidic tar turns into a solidified mass under the catalytic action of sulfuric acid. Due to the prevalence of the sedimentation process when interacting with the components of the reservoir, sulfuric acid can be attributed to sediment-forming reagents.

It should be noted that the NSCS technology is most suitable for cutting off conical water.

Employees of the NPF «Idzhat» developed the technology of MPP + AECP for restriction of water inflows into production wells. The technology consists in sequential alternating injection of acid and alkaline reagents. When they interact, a gel-like mass that is resistant to erosion is formed in the formation, which increases the coverage of the reservoirs with water-flooding. Emissions of carbon dioxide and surfactants formed by the interaction of alkaline reagents with oil, contribute to an increase in the rate of oil displacement.

The main advantages of the MPP + AECP technology are:

Selectivity of exposure to bottom waters.

High thermal stability of the gel mass.

High resistance to the resulting gel to water erosion.

The absence of dispersed particles, which allows for the treatment of wells with low-permeable formations and areas.

High manufacturability and ease of implementation: ready-made reagents are used in the form of commodities, the low freezing point of chemicals allows year-round processing.

When conducting isolation in horizontal wells, the technology developed in «TatNIPIneft» can be used. The essence of the technology lies in the joint use of a plugging composition in the form of a repulsive buffer rim around the horizontal stem (HS) with reliable shielding of this rim by a metal sheath in order to prevent the composition from escaping into the horizontal stem [9]. Since the creation of an insulating screen directly around the HS from quick-hardening compositions is still technically impossible, a metal profile shutter, which is installed in the water inflow interval, is proposed as a screen. The technology includes two successively performed operations: injection into the aquifer interval of the HS of a fringe of a hydrophobic viscous fluid, descent and installation in the water inflow interval of a metal profile blocker of the «TatNIPIneft» structure (RF Patent No. 21119999).

Employees of «TyumenNIIgiprogaz» and Tyumen State Oil and Gas University developed a technology for isolating water in the HS using flexible tubing (FB) [10, 11]. It is based on the sequential injection by the method of outward pouring through the FB of a water-insulating liquid (for example, based on liquid glass) to fill a flooded area of the wellbore. Then, 0.7 m^3 of blocking fluid (for example, based on sulftsel and praestol) is pumped in to fill the remaining part of the barrel. Then, as the wellbore is filled with fluid, the FB is raised to the lift column shoe. Then, FB is again lowered to the level of the flooded interval, the wellbore is filled above the elevator shoe, and, through the FB and filters, they push the water insulating composition into the formation.

In determining the predicted specific efficiency of physicochemical methods, the experience of their use at the analogous fields Samotlor and Lyantorsky was taken into account taking into account the geological and physical parameters of the formations that determine the effectiveness of flow-deflecting technologies [12,13,14].

III. Findings

In reality, flow-diverting technologies can cover 25-50% of the existing stock of injection wells. At the same time, pilot tests of individual technologies are carried out when individual foci of highly watered wells are selected (more than 60%) or with less but equal water content in reacting production wells. As the water content of the produced fluid reaches more than 60-70%, the volume of injection increases, reaching 25-50% of the stock of injection wells.

The analysis of the production of SCR of injection wells in the fields of Western Siberia has shown that the required annual volume of SCR is 10-15% of the operating fund. The annual volume of SCR of producing wells amounts to 25% of the operating fund. The specific efficiency of the SCR of producing wells ranges from 0.3 to 0.7 thousand tons per well – treatment.

It should be noted that the above-described flow-diverting technologies and methods for isolating water inflows are not only applicable, but also necessary for carrying out work to restore the mining well stock of the Chechen Republic.

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