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Justification of technology and fluids for treatment of the unconsolidated carbonate reservoirs

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Abstract
The article describes the features of the structure, the basic operational complexity of carbonate reservoirs of Tatarstan region. Thurn-Famennian complex of the Menzelinsky oilfield is studied in detail. Authors analyzed the drawbacks of applied oil recovery methods and recommended ways to overcome them. The methods of enhanced oil recovery for Thurn-Famennian complex of the Menzelinsky oilfield are suggested on the basis of applied technologies and research of the drawbacks. The authors studied core samples and formation fluids in the laboratory. The article suggests further prospective studies on modeling heterogeneous aquifer.

Keywords: Carbonate reservoirs, heterogeneity, compartmentalization of operational object.

Introduction

Current period of oil production is characterized by deterioration of oil fields structure; involvement in development of low-permeability and highly non-uniform reservoirs, deposits with high-viscosity oil; transition of the main operational objects to a final stage of development with high watercut and low oil yield. Deposits with carbonate reservoirs contain a considerable share of hard to recover oil reserves [1].

According to the American Association of Petroleum Geologists, almost a half of the hydrocarbon reserves of the World (48% oil and 23% gas) is concentrated in carbonate reservoirs. It is known that the main problems during the development of oil&gas fields in carbonate reservoirs are low porosity, fracturing, heterogeneity, high oil viscosity, and, as a consequence of all mentioned - the low values of the recovery factor [2].

The problem of cost-effective production of hydrocarbons from carbonate reservoirs becomes increasingly important due to the reduction of oil reserves in terrigenous reservoirs. Since the carbonate reservoirs are characterized by a high degree of compartmentalization and intermittent of productive formations and the presence of extensive network of fractures and cavities with wide range of sizes and lengths, that’s why, choosing the optimal technology is very difficult [3]. Often, the success of increasing oil recovery, such as flooding, acid treatment is only about 30%, and a significant portion of the wells after the repair work does not go for a payback. This is due to the following reasons:

1) developed technology of pay zone treatment does not take into account all the features of the mechanism of chemical and acid compositions in the carbonate reservoir;
2) a low level of geological and technological support technologies.

Flooding type depends on a set of factors which, on the one hand, connect with a geological structure of a reservoir, physical and chemical properties of oil and formation liquid, on the other hand – with the applied system of wells placement, technology of their construction, production condition of well.

The main reasons of breakthrough into production wells are: reservoir heterogeneity of thickness; areal heterogeneity of reservoir; viscous and gravitational instability of oil replacement; special feature of producing wells placement; inclination of a stratum; existence of high-permeability channels and fractures; leakage of an operational column and cement sheath [4].

Fractures are the main ways for filtration of fluids in the fractured reservoirs because of their high conductivity. However the main reserves of hydrocarbons are concentrated in a matrix with the lowered permeability. For fractured reservoir the advancing water breakthrough of the injected or formation water using the system of fractures are characteristic when developing oil deposits by flooding. Thus oil from fractures is produced quite effectively, and the coefficient of recovery factor reaches 0,8–0,85. Field experience shows that if the reservoir is fractured-porous oil is also produced, however the coefficient of oil recovery is rather small – it doesn't exceed value of 0,3 even for hydrophilic reservoir. Displacement of oil from fractured reservoirs goes under the influence of two major factors: 1) the unsteady pressure gradients in the system of matrix – fractures; 2) process of capillary impregnation. Thus process of capillary impregnation is, as a rule, the slowest [5].

Methodology

One of the major problems during the development of fractured reservoirs is the restriction of water influx into wells that drain fractured layer and also isolation of a high-conductivity single fracture which connects a production well with injection one or with the water-bearing horizon. Breakthrough of the formation or injected water to separate high-permeability layers and interlayers leads to fast increase of watercut of produced hydrocarbons. In these conditions restriction of the movement of water in the high-permeability part of the reservoir becomes a necessary factor for improvement of flooding. The blockage of permeable to water channels with the permeability preservation of an oil saturated part of a layer has to be main objective of waterproof works in an oil well. For this purpose in the middle of the last century enginners started carrying out the polymeric flooding. Additives of polymers lead to increase of water viscosity, reduction of a ratio of mobility of water and oil, decrease in possibility of breakthrough of the water caused by inhomogeneity of layer. However, economic efficiency of such restriction of water influx was low, because of large volumes of reagents injection. Therefore now the preference is given to technologies with the application of small-volume downloadings (fringes) leading to creation of the water isolating blockade in a bottomhole formation zone of production wells. For downloadings in injection wells use cheaper and available reagents [6].

Technologies of water shutoff treatment. Applied technologies that limit the water influx into the well are divided into selective and nonselective. This classification depends on the nature of the effect of injected water shutoff compounds on the permeability of the oil-saturated part of the pay zone. This separation is determined by the physicochemical properties of the material [7].

Non-selective isolation techniques - are methods that use materials which form the screen. Formation of the screen is not dependent on the saturation of oil, water or gas. The screen is not destroyed over time at reservoir conditions. Basic requirements for the non-selective methods of isolation are the precise selection of processed flooded interval and exclusion reduce of the permeability of the productive oil-saturated reservoir. Engineers mainly use cements, foam cements or polymer-technical devices such as drillable packer and block devices. Selective isolation techniques - are methods when using materials are injected into the whole perforated part of the formation [8]. In this case, the resulting precipitate, gel or curing agent is increased filtration resistance only in water-bearing part of the formation. Blockage of the oil saturated part of the formation does not occur. Selective effects of chemicals are based on the difference in physico-chemical properties of reservoir fluids (oil and water) and the physical and geological features of the structure of productive object. These features of the structure are determined by the hydrodynamic features of the reservoir.

Methods of selective isolation are divided into two main groups. The first one is the methods based on using of the selective isolating reagents which form the sediments, soluble in oil and not soluble in water. The second one is the methods based on using of the isolating reagents of selective action which are forming the sediments in a pore space only during the contact with reservoir water and not forming the sediments during the contact with reservoir oil [9].

Classification of water shutoff compositions. The classification of plug-back mixtures and compositions based on the physical and chemical principles of their impact on the pore space taking into account a disperse state and the mechanism of formation of spatial structure in gel and solid bodies is offered. This is done for more reasonable approach of plug-back mixtures choicing. All solutions of chemical compounds and multicomponent dispersions are subdivided into four main types.

Adsorbate - the chemical compounds that are influence the pore or other surfaces. This leads to change of their nature depends on an ionic exchange, chemical or physical adsorption, chemical reaction in a thin film. Adsorbates are: hydrophilizators - the diluted solutions of water-soluble polymers, surfactant; a cation - or anion activating electrolytes - salts, alcali, acids; hydrophobizators - silicoorganic low-molecular compound, fatty acids, surfactant, oil, etc [10].

Fillers - inorganic and organic powders of various dispersions or their suspensions in water or hydrocarbonic liquids. They don't change a physical state at initial stage of injection to the isolated cavities and after filtering out of a liquid phase.

These connections can form spatial structures in gels of polymers, resines and dispersions. That sometimes is followed by superficial chemical reactions. Main representatives of fillers are: the pirogenny silicon dioxides, technogenic aluminosilicates, asbestos, graphite, calcite, sand granulated and not processed waste of solid polymeric materials, mineral and carbon fibers, etc. As a special type of fillers it is necessary to consider firm deposits from discrete particles or units, globule, floccule, which are formed after injecting in the isolated cavities with two or several water solutions. This occurs due to chemical influence of the last or decrease in solubility of initially pumped true solution of polymer of the organic or inorganic types. This type of fillers differs from gels by absence of the spatial structure that unites globules in a coagulative grid of silicon dioxide [11].

Gels - systems with an inorganic or organic firm phase of high degree of dispersion with water or non-aqueous dispersive medium. Spatial structure is characteristic for them. Gels are divided into the following groups:

— the classical - most often has a structure of coagulative type which is formed from primary particles or units, communications between which have low energy. They easily collapse with mechanical influence and are restored at rest. Their isolating properties are based on high penetration and resistance of spatial structure to influence of external aggressive medium;

— partially cured, turning out as a result of interaction of primary gel with fluids, rocks, chemical reagents, temperature transformation or with an introduction of chemically active filler;

— kserogel - the gels that are cured as a result of basement of chemical reactions. They don’t have dispersive medium (solvent).

Requirments for plugging materials. The hardening bonding substances – are the concentrated dispersions of inorganic and organic substances in water and in nonaqueous dispersive mediums. They form strong condensation and crystallizational spatial structure at the whole volume of material after hardening. They are: dispersions organic or silicone resin with chemical hardeners; dispersions inorganic bonding the hydration curing caused by formation of new hydrate connections and their accretion [8].

From the technological point of view methods of isolation of inflow and regulation of a profile of

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acceleration performance of water can be divided on degree of dispersion of the materials isolating (plugging material) into four groups based on use of:
— plugging materials which are filtered into pore space of a layer;
— suspensions of fine plugging materials;
—suspensions of granulated (crushed) plugging materials;
— mechanical adaptations and devices [12].

Inflow of particles into a pore space depends generally on a ratio of the sizes of a pore space and particles of the plugging materials. If a diameter of pore space exceeds diameter of particles in more than 10 times, disperse particles will freely move on pore channels; if diameter of pore space is 3 times less than diameter of particles, particles don't get into pore; if sizes of particles are between the specified limit values, there is a colmatage of pore space when a liquid filtration. It is considered that particles freely move on a fracture if disclosure of width of a fracture exceeds twice diameter of particles [13].

Approximate diameter of pore channels of a reservoir of various types is specified in table 1.

Table 1: Diameter of pore channels in various types of reservoirs

Reservoir type	Diameter of pore channels, mkm^2				
	Permeability of the reservoir, 10^{-15} m^2				
	1-10	10-100	100-500	500-1000	Более 1000
Terrigenous	<5	5-11	11-20	20-26	>26
Carbonate	<6,5	6,5-12	12-22	22-30	>30

Requirements of technical, technological and economic character are imposed to plugging materials [14].

Requirements of technical character define technical capabilities of plugging materials in relation to different conditions. Plugging materials have to:
— possess good fluidity and to keep this property during the time necessary for injection; solution has to get thick and gain durability right after finishing of the injection;
—be able to get into any pore channels and microfractures, but at the same time not to spread in fractures under the influence of their own weight;
—be steady and not to sediment;
—possess good stickiness with casing tubes and rocks;
—have small resistance at the movement in casing tubes and annular space and big resistance at the movement in permeable channels;
— be susceptible to processing for the purpose of regulation of properties in the necessary part;
— not to interact with plugging rocks and reservoir waters with deterioration of properties;
— keep stability at the increased temperature and pressure in a well;
— not to shrink with formation of fractures and to be impenetrable for liquids and gases during curing (hardening).

Requirements of technological character define possibilities of convenient, productive and safe use of plugging materials. They have to:
— easile be able to be pumped over by mud pumps;
—small sensitivity to hashing;
— be inert both in an initial state, and in the final product of curing (hardening) in relation to flushing liquids;
— allow a combination with other solutions;
—be washed away from processing equipment;
— not to be toxic.
Requirements of economic character to initial raw materials:
— has to be not scarce and inexpensive;
— shouldn't worsen the properties at storage [15].

Results Discussion

Core materials and surface samples of oil and water of the Menzelinsky oilfield were taken for laboratory studies. Core samples were solid-liquid extracted with alcohol-benzine blend (30:70) and then dried at 378 K. Two core samples split by a crack during the extraction process. Measurements of porosity and permeability to the air of these cores weren't carried out. Then effective porosity was measured with using of educational-research helium Porosimeter, produced by a company "Coretest System". Calculating the effective porosity we used the law of Boyle-Mariott. For one porosity measurement, we have to perform three operations: calibration setup; the pressure measurement in the core holder after removing cylinders from it; and the pressure measurement in the core holder after core sample is placed in it. Then measurements of the permeability to the air were held at the facility TBP-804. The results of the measurements are presented in table 2.

Table 2: The value of porosity and permeability

# Core sample	Porosity, %	Permeability to air, mD
15^{1b}	9,71	9,40
11^{1b}	6,11	9,54
32^{1b}	9,07	9,71
33^{1b}	3,37	20,05
35^{1b}	5,81	19,43
17^{1b}	4,40	20,69

According to the field report, the porosity varies from 7,6 to 14,0 %, the average is 9,5 %, the permeability is in the range from 1,1 to 8,8 $*10^{-3}\mu m^2$, the average is 2,6 $*10^{-3}\mu m^2$. Values of porosity in the field report agree with the ones we got in the laboratory studies. To validate of the measuring porosity data we also measured it with using X-ray tomography – Skyscan 1174. The scanner has an indoor metal – ceramic X-ray source with long service life, scintillation screen, zoom lens, manipulator for positioning and rotation of the object with the electronic system to power the X-ray source and camera to control the manipulator. This scanner is able to perform the following tasks: to create three-dimensional models of the pore space structure of formation samples (cores); to determine if the formations have heterogeneous lithological inclusions; to study of the structural characteristics of the gel-forming compositions. As a result of measurements the effective porosity is 9,99%.

Values of permeability according to the field report vary with the laboratory studies: three core samples have an average permeability to gas 9,5 mD, three core – 20 mD, two core have a natural fracture, but during the extraction process has been cracked completely. These data is well suited for filtration studies: to simulate a heterogeneous reservoir (highly permeable water-bearing interlayers and low-permeability oil-bearing interlayers), injection of compounds in fractured layers [16].

Field data. Object for the investigation is the reservoir of Menzelinsky oilfield. Commercial oil content is associated with the Upper Devonian deposits, confined to carbonate reservoirs (Thurn-Famennian complex C_{1t}+D_{3fm}), containing about 95% of oil deposits. Specific characteristic of hard-to-recover reserves of Menzelinsky reservoir (according to the classification Halimova E.M.) is composed primarily with dissected (ratio > 3) collectors. The viscousity of the oil at reservoir conditions is more than 30 cPs. Average value of net pay for Tula and Vereisky horizons is less than 3 m. Practical experience has shown that waterflooding of the Tatarstan fields lead to a rapid breakthrough to production wells with aquifer or bottom water and, accordingly, to the fall of the initial oil production rates [17].

Indicator researches were conducted due to the detection of high-permeability channels of a filtration of the injected water in a producing well #. 895 D. Results of injection of the indicator in a producing well showed that the main part of the water that was injected in a well #. 895 D is the share of production wells #. 891 and #. 871 (figure 1). On the basis of the aforesaid it is possible to assume that in the direction of these wells in the reservoir there are channels of the hyperpermeability.

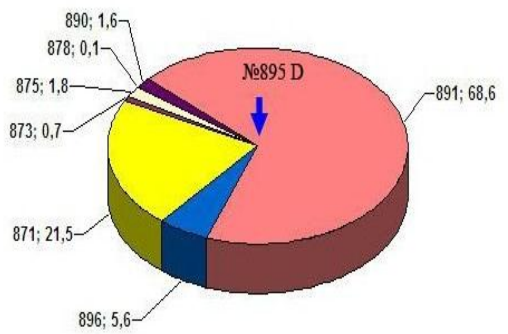

Figure 1: Results of indicator researches of the Menzelinsky oilfield

Thus, about 73 % of produced water of the Menzelinsky oilfield is the share of wells #. 871, 876, 891, 895 and 896. Practically all reasons of wells flooding of the Menzelinsky oilfield are connected with geological and physical features of objects. Today extent of wells flooding speaks, in some cases (wells #. 896, 894), small distances (or their absence) between perforation intervals in wells and water-oil contact. Discrepancy of water content average size of production wells to the extent of reservoir development is also defined by partially coverage process of oil replacement of the area of oilfield. There is partial secondary completion in wells of oilsaturated intervals of operational object.

Heterogeneity and compartmentalization operational object cause the production of multi-speed recovery [18].

The analysis of applied technologies of the Menzelinsky oilfield has shown that the most commonly used technologies of increasing oil recovery are: hydrochloride acid treatment, injecting of polymer systems RITIN-10 in combination with the technology of inflow profile control. The main disadvantage of the injection systems RITIN-10 is a low strength and poor selectivity of the injected composition. As a consequence, watercut of wells continues to increase or remain high (for ex. watercut of the well #876 increased from 50 up to 70%).

On the basis of the analisis of up-to-date technologies of increasing oil recovery, as well as the results of carring out a significant amount of laboratory researches, authors recommend injection of hydrolyzed polyacrylonitrile (0.5-3 % wt.), carboxymethyl cellulose (1-3 % wt.), chromium acetate (0.25-0.5 % wt.) and as a gelatinization controler – chlorine hydride acid and the rest is water [19].This creates a strong water shutoff screen in highly permeable interlayers with a high salinity (255 mg/l) of reservoir water. Selection of carboxymethylcellulose for efficient dewatering agent is proved with the fact that it has a high thermo-oxidative stability, quickly forms a gel in both fresh and saline water and has high viscosity of the solutions even at high shear stresses.

The simulation of filtration tests is planned for further researches to determine of the displacement coefficients with different compositions [1] like: fresh water, mineralized water, wipe with a preliminary injection of solutions of nonionic surfactants [20]. Also we are planning studies to determine the selective ability of the proposed compositions.

Conclusion

As a result of the analysis and laboratory studies it was determined that the selected object (Thurn Famennian complex Menzelinsky oilfield) is fractured with high heterogeneity and compartmentalization. Formation fluids and core samples were prepared within the required range of permeability and porosity for further modeling of heterogeneous reservoir. Also polymer gel composition was selected on the basis of carboxymethyl cellulose and hydrolyzed polyacrylonitrile to simulate the process of limiting the inflow of high water-cut wells.

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