On reasons for the deterioration of the bottomhole formation zone and recommendations for maintaining reservoir properties

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Abstract. The literature on the deterioration of reservoir properties of the bottomhole zone during various operations in the wells and when acting on the reservoir is reviewed. It was revealed that bullhead well control operations and impacts on the bottom-hole formation zone have a very large negative impact if the current geological and physical conditions of the object are not taken into account. Laboratory and field tests of several hydrocarbon-based emulsion formulations were performed. Experiments and tests have shown the effectiveness of the proposed formulations and allow recommend them for use in well repair.

1. Introduction

The Samotlorskoe field, like most oil and gas fields, is developed using the method of flooding oil deposits. At present, the water cut of products has exceeded 90 %, but the achievement of the planned oil recovery can no longer be achieved only by applying the methods of increasing oil recovery. The provision of rational development is possible with a working stock of wells, the bottom-hole zone of the formation of which does not create obstacles to the influx of hydrocarbons.

Field experience in the development of gas and oil fields shows that during the primary and secondary opening of productive deposits, development, bullhead well control and flushing of wells, in general, during the operation of wells, the filtration-capacitive properties of BHZ (bottom hole zone) as a result of leaching of filtrates and solid phase from various technological solutions based on water, which are often used at present. For reservoir resuscitation, a number of additional impacts on the formation have to be performed, and this leads to a significant increase in the cost of repair work, lengthening of the repair time, and the natural reservoir properties of the producing formation are not always restored.

The appearance of residual oil in the BHZ and in remote reservoir zones is determined by the geological and physical conditions of the deposits, the type of wettability of the pore surface, the
composition, physicochemical characteristics of the fluids saturating the reservoir, the evolution of the reservoir-fluid system during reservoir development and operation of individual wells [1–4].

Well operation depends on a number of factors: geological heterogeneity of section, quality of opening and development of productive formations, technological factors associated with the operation of wells in field development, etc. [1, 3–6]. The factors causing the deterioration of filtration-capacitive properties of BHZ can be geological, and technical and technological. They can be conditionally divided into groups:

- geological and physical characteristics of reservoir (reservoir type, porosity, permeability, composition and properties of formation fluids, etc.);
- technical and technological parameters of drilling (drilling method, drilling fluid, the duration of contact of the exposed formation with process fluids, etc.);
- technical and technological parameters of the secondary opening and development of reservoir (type of perforator, perforation fluid, method of development, etc.);
- technical and technological parameters of well operation (bottomhole pressure, temperature in the bottomhole formation zone – BHZ, etc.).

A significant reason for the decrease in BHZ permeability during well development is the penetration of solid clay particles of drilling fluid into the formation, and this phenomenon is enhanced in highly permeable reservoirs [1, 4, 5]. With increasing well downtime, i.e. contact of the formation with foreign liquids, these negative consequences become even greater. For example, for the wells of the Langepasskoe group of fields, the radius of contaminated zone is 0.08–0.8 m [7], for the Shaimske group of fields, the filtrate penetration into the BHZ is more than 0.1 m [8], and for the Megionskoe group of fields up to 1.5 m, and in some cases the filtrate penetration zone can reach 3 m or more [5]. Already at an early stage of oil field development, the state of BHZ is significantly worsened, and the decrease in permeability compared with the natural one reaches 50 % or more [5].

BHZ mudding drastically reduces drainage coverage. It is known that the coverage of a productive formation by drainage (selection in production wells) depends on the coverage of the productive formation by injection in injection wells [6–9]. So, for oil fields in Bashkiria, Tatarstan, Western Siberia, etc., the coefficient of formation coverage by water flooding along the thickness of the layer in injection wells is 0.2–0.6, and water is absorbed mainly by the most permeable layers.

The presence in the formation of clay interlayers of different thicknesses or clay components in the composition of the mineral (maybe 1–3 to 25 %) skeleton strongly affects the injectivity coefficient of water injection wells. If water is pumped into the oil reservoir that is chemically different from highly saline or fresh water, then it interacts with clay inclusions in the rock, destroying them, and the rock swells. Such a process causes clogging of the filtration channels, a decrease in the permeability of BHZ and the coefficient of coverage by waterflooding of the reservoir in thickness.

At West Siberian oil fields, it was revealed that the average duration of the development process after repair of wells plugged in front of it with an aqueous solution of NaCl reaches 4–5 days, the operating mode established before the repair is reached only after 40–60 days. Thus, there is a shortage of oil associated with the development and withdrawal of wells to a stable operating mode equal to 400–600 tons for one well repair [10–12]. For example, until 1988, in the wells of the Urengoiskoie and Iamburgskoe oil and gas condensate fields, work on opening, killing and preservation was carried out using clay and aqueous solutions of calcium chloride. After such plugging and further repair of the well, the rate of gas condensate wells in Valanzhisiske strata fell by 60–63 % of the initial (or design), for the Senomanskie gas wells, the average drop was 20 %. Since 1988, the use of invert-micellar fluids has begun. As a result, the duration of well development decreased, but with a natural decrease in reservoir pressure in the period 1994–1996, this time reached 40–50 days. And for wells where water-based jamming solutions were used, the development time was 120–130 days. Recently, a decrease in the duration of well development to 12–14 days has been noted, which is due to the use of hydrocarbon-based bullhead well control solutions.

2. Methods and materials
Analytical studies were carried out to clarify factors of deterioration of formation properties around wells and established characteristic reasons for the decrease in reservoir characteristics. Laboratory studies were conducted to develop recommendations for preserving reservoir properties. In the studies, core samples with different permeability and mineral composition were used; compositions containing surfactants, fillers were filtered. To verify the results of laboratory experiments, field trials of developed formulations of process fluids were conducted.

3. Results

The reviewed literature on the mechanisms of mudding of the bottom-hole formation zone showed that most of the damage to the formation in the bottom-hole zone occurs when the formation is opened during drilling and well development, repair work in wells (bullhead well control, flushing, etc.). They significantly reduce filtration-capacitive properties of formation of bottom-hole treatment zone, which do not take into account geological and physical features, as well as the change in thermodynamic conditions in formation.

One of the ways to preserve reservoir properties at BHZ is to modify bullhead well control fluids. As modifying agents can be used, for example, IVV-1, GF-1, Seanec-TU.

Filtration experiments were carried out to pump surfactant compositions through physical models of the Kalchinskogo, Poluniakhskogo, Severo-Demianskogo and Severo-Kachkarskogo deposits. The studies show that the coefficient of recovery of permeability of core samples after pumping through bullhead well controls, which contains KCl (or K2CO3) and GF-1, reaches 1.02–1.03, i.e. there is an improvement in reservoir properties of the rock, due to a decrease in surface tension at the phase boundary ‘fluid of bullhead well control’ there is an increase in core permeability.

Alternative formulations for fluids of bullhead well controls and water-based wash solutions are hydrocarbon-based compositions, invert and hydrophobic-emulsion solutions, the external phase of which is represented by a non-polar medium.

A hydrocarbon-based solution was developed containing oil, low molecular weight water-soluble alcohols C1–C1, aluminum naphthenate (thickener), barite / bentonite clay (weighting agent). The Lauroylmethyl-Alkylammonium salt of naphthenic acids with the general formula \( \text{Al(OH)}_2(\text{OCOR}) \) (here R is naphthyl), dissolving in oil and / or hydrocarbons forms high molecular weight associated complexes that thicken the oil or hydrocarbon solution.

For bullhead well controls of gas and gas condensate wells, hydrocarbon-based invert emulsion formulations have been developed. Such compositions can be used as a fluid of bullhead well controls and / or blocking composition to protect the collector from clogging and damage. An emulsifier (e.g., an emulsifier), a structure-forming agent, a fibrous filler (FF) with diphilic properties and a finely dispersed filler (DF) of a carbonate nature were introduced into the composition of these systems; the dispersed phase is an aqueous solution of calcium or potassium chloride. For filtration experiments, samples of polymeric sandstone with various reservoir properties were used. Physical modeling of the emulsion system (ES) of gas and gas condensate reservoirs was performed.

The analysis of experimental results showed that the permeability of cores is not completely restored when using compositions without fillers. In low-permeability core samples (less than 50–10^3 \( \mu \text{m}^2 \)), permeability is restored more than with average values ((50–100) · 10^3 \( \mu \text{m}^2 \)) and at high permeability (1–2 \( \mu \text{m}^2 \)) (table 1). In the experiments, a base emulsion without fillers was used, having the composition: diesel fuel – 40 %, saturated NaCl solution – 60 %, emulsion – 4 %, FFAT-1001 – 1 %.

| Air permeability, 10^3 microns² | Recovery factor, \( K_r \) |
|-------------------------------|--------------------------|
| 247                           | 0.380                    |
| 731                           | 0.125                    |
| 902                           | 0.157                    |
| 1796                          | 0.205                    |
When using ES with DF in all cases, a crust formed on the end surface of core samples. The thickness and stability of the crust from DF depend on the structural features of the pore space, i.e. from permeability. On samples with high permeability, the formation of a crust is thicker, with greater stability. With a small sample permeability, the DF crust will be thinner and less durable.

When the depression reached 5.0 MPa, the process of “removing” the introduced emulsion system from the pore space easily began, and the filtration began almost immediately when the depression reached 5.0 MPa. This result was obtained in all tests performed. When an inflow is induced in gas wells, the depression on the formation can reach 10–15 MPa, in oil wells, a depression of 5.0 MPa can also be achieved practically.

The results of filtration experiments are shown in table 2.

| № | Type of solution | DF, % | FF, % | Air permeability of the sample, $\cdot 10^{-3} \mu m^2$ | Permeability recovery coefficient, kV |
|---|-----------------|-------|-------|-----------------------------------------------|-----------------------------------|
| 1 | Base emulsion   | –     | –     | –                                             | –                                 |
| 2 | № 1+           | 1.0   | –     | 194                                           | 0.71                              |
| 3 | № 1+           | 3.0   | –     | 216                                           | 0.66                              |
| 4 | № 1+           | –     | 1.5   | 504                                           | 0.69                              |
| 5 | № 1+           | –     | 1.5   | 278                                           | 0.62                              |
| 6 | № 1+           | –     | 3.0   | 177                                           | 0.90                              |
| 7 | № 1+           | –     | 3.0   | 300                                           | 0.60                              |
| 8 | № 1+           | –     | 5.0   | 243                                           | 0.86                              |
| 9 | № 1+           | –     | 5.0   | 401                                           | 0.87                              |
| 10| № 1+           | –     | 5.0   | 550                                           | 0.92                              |
| 11| № 1+           | –     | 5.0   | 998                                           | 0.95                              |
| 12| № 1+           | –     | 5.0   | 1233                                          | 0.70                              |
| 13| № 1+           | –     | 8     | 1673                                          | 0.93                              |
| 14| № 1+           | –     | 10    | 1480                                          | 1.0                               |
| 15| № 1+           | –     | 10    | 2195                                          | 1.0                               |
| 16| № 1+           | 1.0   | 3.0   | 300                                           | 0.98                              |
| 17| № 1+           | 5.0   | 3.0   | 297                                           | 1.0                               |
| 18| № 1+           | 5.0   | 5.0   | 401                                           | 1.0                               |
| 19| № 1+           | 5.0   | 6.0   | 1480                                          | 1.0                               |
| 20| № 1+           | 5.0   | 8.0   | 1673                                          | 1.0                               |
| 21| № 1+           | 5.0   | 10.0  | 2195                                          | 1.0                               |
| 22| № 1+           | 6.0   | 11.0  | 2258                                          | 1.0                               |

Laboratory studies have shown the high efficiency of using ES with fillers to preserve reservoir properties in BHZ. Field trials showed an acceleration of the output of wells into operation by 3–5 days in comparison with the start-up of wells after repairs, where other process fluids were used. Therefore, it can be recommended for the use of ES with fillers during repair work in production wells.

The investigated emulsion systems can be used as washing liquid, killing liquid, and some compositions can be used as blocking pastes for installing a “viscous” packer in the interval of the reservoir to protect it from damage.

4. Conclusion

Separate laboratory studies and field trials have shown that technological fluids for well repair can protect the bottom-hole formation zone from damage and ensure permeability recovery after repair. The call of inflow and well output to the operating mode is significantly accelerated.

It is proposed to use hydrocarbon-based process fluids for killing wells and for flushing, as well as to modify these fluids with the addition of water repellents and special fillers, which protect the formation from clogging with filtrates and mechanical impurities and ensure recovery of reservoir permeability after repair work in the well.
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