Isolation through a viscoelastic surfactant of a fracable hydrocarbon-containing formation

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Abstract: In this paper water cut of well products problem is considered. To solve this problem it is proposed to use a technology of water inflows isolation during the drilling process developed by the authors. Not only does our approach stimulates the production of hard-to-recover hydrocarbons but it also protects local water and undisturbed geological formations against the impact of hydraulic fracturing operations. This approach also enables higher well potential due to a longer service life of the wellbore. The use of a device-pressure regulator with synchronous injection of the developed blocking fluid is presented. Mathematical modeling of the experiment was performed, aimed at determining the dependence of the change in pressure drop in the annular space of the well on the flow conditions of the blocking composition with a device installed in the bottom hole assembly that will effectively apply the controller device, taking into account the drilling parameters of a particular well. The novelty of this approach lies in the fact that this work offers an aquifer isolation technology, which suggests applying a pressure regulating device, and provides a layout of a blocking viscoelastic system.

Keywords: stimulation; hard-to-recover hydrocarbons; hydraulic fracturing; oil exploration ecology.

1. Introduction

The volumes of oil and gas production in Russia are mostly carried out at the fields, the development of which belongs to the last decades of the last century. In terms of their development and operation, there is a depletion of reserves and a decrease in reservoir pressures. The long development time contributes to the complication of the conditions for the construction of wells in these fields, especially in ensuring zonal isolation reliability, which is facilitated by a large hydraulic connection between them.

Water cut of well products of fields in Western Siberia, the Urals and the Volga region continues to increase and today exceeds 90% on average [6, 15]. Until recently, the oil and gas production in Russia has been developing rather extensively [9], the recovery factors were low, ranging from 20+% to 40+, and demonstrated a steady downward trend [2]. In such conditions, qualitative changes in the practice of hard-to-recover hydrocarbon extraction are needed. Recently, the new stimulation technologies have become on the forefront in the Russian oil and gas sector [5]. To effectively and efficiently extract unconventional resources, the industry is already spending a lot to optimize completion processes and stimulate production. For instance, an extensive campaign was carried out in 2015 at the Priobskoye and Prirazlomnoye oil fields located in the Khanty-Mansiysky District. The main task during all operations was to cope with multi-stage hydraulic fracturing. Different approaches to isolation were used and our work takes into account this
experience. Additionally, the positioning and number of perforating stations were determined as a critical parameter. The first operating data on small-diameter well productivity was highly encouraging with a length of the wellbore section being small. Such undertakings may be recognized as an effective method for improving the recovery of hydrocarbons from mature fields [13]. Often, however, such an approach is not time and cost-effective. With technologies designed for hydraulic fracturing modeling, we can assume that improve the economic efficiency of the process, hydraulic fracturing must be carried out in a controlled manner on isolated enclosing formations. This will reduce the process cost and increase the economic efficiency of the industry. Stable profitability of field development can be achieved by reducing the cost of oil production, which is 30-50% dependent on the volume of operating and energy costs, as well as the cost of repairs. High quality sealing of oil and gas wells, reducing cross-flow flows is the most important condition for their effective use as long-term structures. The sealing devices used in this process should allow for a variety of well work to be carried out without fail and ensure that the technical, environmental and economic requirements are met.

This work aims to introduce new methods for the enhancement of oil and gas production through the recovery factor improvement. We plan to achieve this goal by optimizing the existing stimulation processes, specifically by applying new viscoelastic surfactants to isolate the fracking area from the water horizons. Not only will this ensure a good boost to production but also the production costs will be reduced due to lower environmental risks and longer life cycle of the well. Enhanced oil recovery is obtained here by introducing into the development of low-permeable reservoirs of the Bazhenov formation. Generally, enhanced oil recovery is carried out by multi-stage hydraulic fracturing, the implementation of which involves the creation of high pressures up to 120 MPa and the flow rate of fracturing fluid more than 0.12 m³/s.

It should be noted that conducting hydraulic fracturing with the above parameters leads to a violation of the integrity of the cement sheath and cross-flow between beds at the boundaries of the oil-water contact. For a high-quality hydraulic fracturing, it is necessary to effectively isolate the upper aquifers. In order to reduce cross-flow between beds in the development of fields with hard to recover reserves, preliminary isolation of water-containing formations is required.

2. Materials and methods

There are several technological directions to solve the problem of high-quality isolation of aquifers. For example, the most frequently used is the selective isolation of water bearing formations during remedial cementing temporary blocking the reservoir, and the PBL technology (Circulation Sub). This device contains a circulation valve, which allows you to repeatedly switch the flow of fluid from the internal space of the drill string to the annular, bypassing all the bottom hole assembly (BHA) layout elements that are in the layout below the PBL [3]. However, the use of this technology does not provide the regulation of pressure in the annular space [7]. To ensure work aimed at improving the efficiency of well completion at uncontrolled flow intervals, it is proposed to use a pressure regulator device during drilling with simultaneous injection of a blocking fluid (Fig. 1) when drilling-in the aquifer initially [8].
Figure 1. Pressure control device. 1 – pressure regulator; 2 – rubber element; 3 – metal collar; 4 – drilling bit; 5 – water-bearing formation; 6 – annular gap

Water zone isolation during drilling is carried out as follows. The device pressure regulator 1 is installed in the BHA. It contains a rubber element 2 with an outer metal ring 3. The distance from the bit 4 to the pressure regulator is selected based on the power of the aquifer interval 5. During the drilling process, the device is activated to reduce / increase the annular gap 6. Then the calculated volume of the blocking fluid is injected (table 1)[1,11].

The correction of the hydrodynamic pressure and equivalent circulation density (EDS) is carried out by changing the mechanical drilling speed, which affects the concentration of mud in the annular space and the flow rate of the cleaning fluid.

In order to avoid differential sticking of the boring tool, a prerequisite is its periodic or constant rotation.

Using the developed technology when drilling intervals of aquifers, the drilling mud can be replaced with a blocking fluid.

3. Results and discussion

Despite the fact that presently there is already a fairly wide range of different compositions for remedial cementing to limit water inflows, work is underway to create new and improve the already developed blocking compositions in order to improve the technical result from their use and reduce the cost of the work of this kind.

To date, compositions based on cement with various polymer additives that improve their adhesion and elastic properties; powdered materials; formulations based on organosilicon compounds; polymer and gel-forming compounds, etc. are used to carry out water shut-off works. Various combinations of reinforcing compositions are also used, the advantage of which is the ability to control their properties depending on the conditions of use.

Of the variety of the proposed water shutting compositions, the use compositions of viscoelastic systems (VES) are one of the most promising ways to block aquifers in the drilling process. With this method of water isolation, a gel-like composition is pumped into the well, which at the initial moment is a low-viscosity fluid. After a certain period of time, there is a sharp increase in viscosity until the system thickens, i.e. the solution loses its fluidity and, directly in reservoir conditions, turns into a gel that is capable of blocking water-producing horizons.

However, most of the currently known viscoelastic water shutting compositions have a number of disadvantages, among them: low penetration, instability in reservoir conditions, toxicity and high
cost. The elimination of these shortcomings can significantly increase the competitiveness of this method of restricting water inflows.

In order to preserve the reservoir porosity and permeability of the formation, the main indicators of the properties of the blocking fluid were determined.

Table 1. Parameters of blocking fluid.

| The name of indicators properties of blocking fluids | Recommended parameters |
|-----------------------------------------------------|------------------------|
| Relative viscosity, c                                | 50-250                 |
| Plastic viscosity, \(\eta_f\), mPa·s                 | Not less than 65       |
| Dynamic shear stress, \(\tau_d\), dPa               | 400-1000/150-700      |
| Static shear stress\(010s/10\) min, dPa             | Not less than 15/15    |
| Filtration rate \(f\), cm\(^3\)/30 min              | Not more than 5       |
| Filter cake thickness of the, mm                     | 0.5-1.0 mm             |
| pH                                                   | 7-8                    |
| Thermal stability, °C not less than 90              | Not less than 90       |
| Sedimentation stability, kg / m\(^3\)               | Not more than 20       |
| Daily sludge, %                                      | Not more than 4        |

The main requirements for the blocking compositions when drilling wells are high viscosity, wide control limits of structural-mechanical and rheological properties, low filtration rate, preservation of reservoir properties and operational characteristics of the reservoir (with the likelihood of penetration into the productive horizon), lack of source components, simple technology of preparation in field conditions, ensuring the safety of work.

To block high permeability zones, it is necessary to use a plugging agent whose dimensions depend on the pore size of the formation. The most suitable for this purpose is calcium carbonate of coarse grains or microspheres (glass, aluminosilicate or ceramic).

Constituents used in the fluid for zonal isolation should meet the requirements:

1. must be chemically inert to rocks and formation fluids;
2. the filtrate of the blocking mixture should be inhibitory to clay particles;
3. must be thixotropic;
4. should have a low corrosive effect on downhole equipment;
5. must be thermostable and cold-resistant;
6. should be non-flammable, explosion and fire safe, non-toxic.
7. must be technologically advanced in the preparation and use.
8. should be susceptible to the regulation of the properties of chemical processing.

Thus, the development of a composition for blocking water bearing formations, which minimizes fluid movement in the well-reservoir system and contamination of the bottomhole formation zone, as well as eliminating cross flow between beds, is a highly relevant task, and the resulting composition requires a comprehensive study.

In accordance with the recommendations on the component composition, in the laboratory, mixtures were prepared, with which experimental studies were carried out [4,12]. The following reagents were selected as the base component of the solutions:

- Surfactant (foaming agent and collector);
- pH adjuster (water softener);
- biopolymer;
- carbonate filler (weighting agent, gelling agent);
bactericide.
The concentration of surfactants, stabilizing and gelling components were varied. The optimal solution recommended for use was with the following composition:

| Component         | Percentage |
|-------------------|------------|
| Biopolymer        | 0.3        |
| Filtration controller | 0.5      |
| Carbonate filler  | 0.7        |
| Surfactant        | 0.04       |
| PH regulator      | 0.06       |
| Bactericide       | 0.06       |

The proposed composition has the properties presented in table 2.

**Table 2.** The main physico-chemical and rheological parameters of the blocking foam mud.

| Properties                  | Test temperature |
|-----------------------------|------------------|
|                             | 20°C  | 90°C  |
| Density, kg/m³              | 800   | 800   |
| Relative viscosity, s        | 220   | 200   |
| Foam expansion               | 1,60  | 1,58  |
| Stability, kg/m³             | 0     | 0     |
| pH                           | 7.2   | 7.2   |
| Filtration, cm³/30min        | 8.0   | 9.0   |
| Filter cake thickness, mm    | 1.5   | 1.0   |
| Effective viscosity, Pa·s    | 0.004 | 0.003 |

The density of the fluid, the rheological properties of the solution, the flow rate of the cleaning liquid, the composition and amount of rock (mudstones) [1, 10, 14]) were used as input parameters for the simulation of the experiment. This experiment was aimed at determining the dependence of the change in pressure drop in the annular space of a well on the flow patterns of a blocking compound with a device installed in the BHA. For effective use of the regulator device, using the needed drilling parameters, dependencies were formed using the Darcy-Weisbach formula:

\[ \Delta P = \gamma \frac{\rho v^2 l}{D_w - d_{w\text{il}}} \]  
\[ \gamma = \frac{96}{Re} \]  
\[ Re = \frac{\rho v f}{\mu} \]  
\[ f = D_w - d_{w\text{il}} \]  
\[ \Delta P = \frac{96 \cdot \mu v^2 l}{f} \]

where \( \rho \)=the density of the drilling fluid (kg/m³); \( v \)=the average velocity in the annular cross-section (m/s); \( f \)=the gap between the borehole walls and the regulator (m); \( \mu \)=the effective viscosity (Pa·s); \( l \)=distance from the bottomhole to the device-regulator (m).

The following parameters were used for the simulation: \( \rho = 800, v = 0.15, f = 0.038, \mu = 0.003, l = 50 \). The dependence of the pressure change on the change in the effective viscosity of the solution is shown in Fig. 2.
Figure 2. The dependence of the pressure change on the change in the effective viscosity of the solution.

Figure 3. The dependence of the pressure change on the change in the average velocity over the cross-section of the annular space.

It can be seen from the graph that as the effective viscosity decreases, the pressure in the well increases. At $\mu = 0.003 \text{ Pa} \cdot \text{s}$, the pressure in the interval from the bottom hole to the regulator device will be $7.579 \cdot 10^8 \text{ Pa}$.

The dependence of the pressure change on the change in the average velocity over the cross section of the annular space is shown in Fig. 3.

From the graph it is seen that with increasing speed, the pressure in the well increases. At $\vartheta = 0.15 \text{ m/s}$, the pressure in the interval from the bottom to the regulator device will be $1.011 \cdot 10^4 \text{ Pa}$.

The dependence of the pressure changes on the change in the gap between the walls of the well and the device-regulator is shown in Fig. 4.

Figure 4. The dependence of the pressure change on the change in the gap between the walls of the well and the device-regulator.
Figure 5. Dependence of pressure change on the distance between the device-regulator and the bottomhole.

From the graph it is seen that as the gap decreases, the pressure in the well increases. At $f = 0.02$ m, the pressure in the range from the bottom to the regulator device will be $2.16 \cdot 10^8$ Pa. The dependence of pressure changes on the distance between the device-regulator and the bottom, i.e. from the height of the aquifer, is presented in Fig. 5.

From the graph it is seen that with increasing length the pressure in the well increases. At $l = 50$ m, the pressure in the range from the bottom to the regulator device will be $1,496 \cdot 10^4$ Pa [8].

4. Conclusion

Based on the analysis of results of the research, it can be concluded that the application of isolation technology using the proposed equipment at a constant drilling rate, with a change in the effective viscosity and simultaneous adjustment of the gap in the annular space will ensure the isolation of a water-saturated reservoir.

The effectiveness of the proposed technology is ensured by blocking the reservoir with the proposed VES composition and reliable water zone isolation for an extended period of time, which reduces the water-cut of well production.

If employed on a large scale, our approach to the problem of stimulating the production of hard-to-recover hydrocarbons is expected to enhance production and minimize environmental risks in hydraulic fracturing. This allows expecting an increase in industry profitability due to higher economic efficiency of production. We consider it important to take into account the potential environmental risks in project evaluations and to plan stimulation steps better so as to accomplish as complete elimination of these risks as possible. An approach in point is well-described in this work.

References

[1]. Altunina, L. K., Kuvshinov, V. A., Kuvshinov, I. V., & Stasieva, L. A. (2019). Enhanced Oil Recovery Technologies for Arctic and Siberian Regions. IOP Conference Series: Materials Science and Engineering, 696(1), 012001.
[2]. Cherepovitsyn, A., Fedoseev, S., Tcvetkov, P., Sidorova, K., & Kraslawski, A. (2018). Potential of Russian Regions to Implement CO2-Enhanced Oil Recovery. Energies, 11(6), 1528.
[3]. Gasumov, R. A., Dubenko, V. E., Minchenko, Yu. S., Belous, A. V., & Selyukova, V. N. (2015). The use of gel-forming systems for temporary blocking of the gas reservoir during the cementing of wells with open bottom. Bulletin of the Association of Drilling Contractors, 1(2), 13-16.
[4]. Gasumov, R. A., & Kashapov, M.A. (2009). Development of foaming compositions for drilling and repair of wells. Construction of oil and gas wells on land and at sea, 12, 30-32.
[5]. Guo, Y., Weng, D., Wang, X., Duan, Y., Xiu, J., Chen, Z., & Tang, M. (2019, October). Optimization on Well Energy Supplement and Cluster Spacing Based Upon Fracture Controlling Fracturing Technology & Reservoir Simulation-An Ordos Basin Case Study. SPE Russian Petroleum Technology Conference. Society of Petroleum Engineers.
[6]. Kontorovich, A. E., Eder, L. V., & Filimonova, I. V. (2017, September). Paradigm oil and gas complex of Russia at the present stage. IOP Conference Series: Earth and Environmental Science, 84(1), 012010.
[7]. Kuchin, V. N. (2018). Substantiation and development of technology to isolate water
inflows when drilling in the range of anomalous reservoir pressures (pp. 199-204). 72nd International Youth Scientific Conference.

[8]. Kuchin, V. N., Tsygelnyuk, E. Yu., Nutskova, M. V., & Dvoinikov, M. V. (2018). Improving the technology of isolation of water inflows during drilling in the range of abnormal reservoir pressures. *Oil and gas business, 16*(4), 51-58.

[9]. Moe, A., & Rowe, E. W. (2010). Chapter Five Northern Offshore Oil and Gas Resources: Policy Challenges and Approaches. *Russia and the North, 107*.

[10]. Montman, R., Sutton, D. L., & Harms, W. M. (1983). Foamed portland cements. *Oil and Gas Journal, 20*, 219-232.

[11]. Rosa, L., Rulli, M. C., Davis, K. F., & D’Odorico, P. (2018). The water-energy nexus of hydraulic fracturing: a global hydrologic analysis for shale oil and gas extraction. *Earth’s Future, 6*(5), 745-756.

[12]. Rozieres, S. D., & Ferriere, R. (1991). Foamed cements characterization under the downhole conditions and the Job Design. *SPE Prog. Eng, 3*, 297-304.

[13]. Serdyuk, A. N., Frolenkov, A. N., Valeev, S. V., Sitdikov, S. S., Shchekaleva, T., Roukhlov, V., ... & Gromovenko, A. V. (2016). Multistage Stimulation of Sidetrack Wellbores Utilizing Fiber-Enhanced Plugs Proves Efficient for Brown Oil Fields Development. In *International Petroleum Technology Conference*. International Petroleum Technology Conference.

[14]. Silin, M. A., Rud, M. I., Davletshina, L. F., Gubanov, V. B., Magadov, V. R., Fedorova, L. A., & Kyong, F. Kh. (2010). Development of bitumen emulsion for use in the technology of selective isolation of water inflows. *Construction of oil and gas wells on land and at sea, 11*, 11-13.

[15]. Sushko, O., Plastinin, A., & Saruchev, V. (2017). Investments in oil production and development in conditions of oil price stagnation. In *International Conference on Trends of Technologies and Innovations in Economic and Social Studies 2017*. Atlantis Press.