Technological fluids on biopolymer basis for repair wells

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Abstract. The article describes the commercial experience of using various compositions of process fluids during repair and insulation works and substantiates the practical value of solutions on a biopolymer basis. The results of laboratory studies are presented and the compositions of process fluids on a biopolymer basis for well repair are proposed. The preservation of the natural permeability of the reservoir in the near-wellbore zone is one of the main requirements for quality well repair. However, as the field practice shows, the overhaul is almost universally carried out with the use of process fluids, the parameters of which are chosen without taking into account the specific geological conditions, the lithologic and physical properties of the reservoir and the physicochemical characteristics of its fluids.

1. Introduction
The cost of biopolymer systems is higher than that of traditional process fluids containing synthetic polymers, but their use is economically beneficial, since it minimizes the negative impact on the productive layer, and the development time of wells decreases after carrying out repair work.

Repair and restoration work (RRW) are accompanied by killing and temporary blocking of the well bottom zone. One of the main reasons for the loss of productivity of wells in fields and underground gas storage facilities (UGS) with a large capacity of highly permeable reservoirs is an unreasonable approach to the use of process fluids. RRW wells without taking into account their physicochemical characteristics and geological and physical features of reservoirs, leads to intensive absorption of working fluids, loss of circulation, deterioration of filtration-capacitive properties (FCP) of productive formations, a sharp decline in well productivity. Therefore, the development of compositions of process fluids for plugging with temporary blocking of the bottom hole zone during well repair to prevent contamination of the bottom hole formation zone (BFZ) is an actual problem for many fields and UGS.

2. Relevance of the topic
The analysis of works devoted to the study of improving the performance of gas wells in various geological conditions, allows summarizing the theoretical and practical research data, as well as identifying the requirements for the gel-forming compound for temporary blocking of the BFZ: manufacturability (the content of the minimum number of components, simplicity download); homogeneity; inertness to the rocks composing the reservoir; do not reduce the permeability of the BFZ; possess gas retention capacity and exclude fluid migration pathways through the BTC; have high values of adhesion strength with enclosing surfaces; complete removal from the well by a pressure drop that does not exceed the critical depression on the formation (exclude the use of chemical processing of the PPP).
3. Essence of the issue
The analysis of some known compositions of process fluids for the construction and repair of wells is presented below.

The authors of the fastening technology [1] propose an annular space (BTC) of the production casing above the reservoir filled with a viscous fluid trap with a density that provides hydrostatic pressure above the reservoir by 5–10%. A composition based on monoethanolamine, polyacrylamide, aluminum sulphate, drilling mud and anticorrosive inhibitor can be used as a viscous hydraulic seal. The proposed water seal has a reduced strength, which is associated with the ingredient composition, in particular the type of cross-linking system. The use of a trivalent metal salt as a gelling agent provides a weak three-dimensional structure of a cross-linked polymer. In addition, the water seal has insufficient plastic strength, over time, syneresis can occur – the separation of water incorporated into the cross-linked polymer. As a result, gas migration may occur from the reservoir to the BTC. Also, this composition has a reduced adhesion, in connection with which it is not possible to use it effectively.

One of the new ways to create sealing screens in MCD warning technologies is the use of a hydraulic seal [2–5]. The hydraulic lock is understood to mean a working fluid with the required technological properties, which forms an impermeable screen in the well BTC, preventing gas from entering the cement stone and preserving the reservoir proper-ties of the formation.

The insulating material of the water seal in the work [4] includes used drilling mud, poly-acrylamide, ferrochrome lignosulfonate, carboxymethylcellulose, and a corrosion inhibitor. Additionally, the solution may contain bentonite, chalk or gypsum. This compound has a fast gelation, resulting in a difficult-pumped system, the use of which may be limited due to the inability to pump the compound to the depth of the reservoir. The increase in viscosity can also be facilitated by the presence of solid filler over the optimum with given amounts of the polymers used.

In the work [6], a three-phase foam is used, which is unstable and changes its properties in time. Upon contact with the reservoir water, the liquid phase of the foam dissolves in it, and the foam collapses, which leads to imbalance "well-reservoir". Foam has a low gas breakthrough gradient, which is why it is pumped into the well to the mouth.

![Installation diagram for the study of the blocking ability of process fluids](image)

**Figure 1.** Installation diagram for the study of the blocking ability of process fluids: 1 – high pressure hydraulic press; 2 – capacity for oil; 3 – receiving valve; 4 – discharge valve; 5 – valve for pressure relief; 6 – hydraulic cylinder; 7 – manometer; 8 – filtration chamber; 9 – piston return screw; 10 – measuring capacity; 11 – permeable medium model; 12 – separation piston

**Table 1.** Effect of known blocking compounds on the permeability of artificial sandstone
| № exp. | Blocking fluid | № of sample | t water bath, °C | Repressio, MPa | Breakpressure, MPa | K0, mcm² | K0, mcm² | β, % |
|-------|----------------|-------------|------------------|----------------|-------------------|----------|----------|------|
| 1     | Water          | 11a         | 20               | 0              | -                 | 0.28     | 0.1      | 51   |
|       |                | 4a          | 20               | 0              | -                 | 0.75     | 0.4      | 55   |
|       |                | 6a          | 20               | 0              | -                 | 0.79     | 0.6      | 76   |
|       |                | 9a          | 20               | 0              | -                 | 0.96     | 0.8      | 93   |
| 2     | Clay solution  | 1           | 50               | 3.5            | 0.20              | 0.10     | 0.0      | 75   |
|       | Weighted with barite | 2   | 50               | 3.5            | 0.06              | 1.02     | 0.7      | 88   |
| 3     | Clay solution  | 1a          | 50               | 3.5            | 1.10              | 0.25     | 0.2      | 91   |
|       | thickened with CMC  | 2a | 50               | 3.5            | 0.06              | 0.15     | 0.1      | 94   |
| 4     | Blocking fluid + chalk | 3   | 50               | 3.5            | 0.06              | 0.14     | 0.0      | 71   |
| 5     | Blocking fluid + filler | 4       | 50               | 3.5            | 0.06              | 0.75     | 0.2      | 35   |
|       |                | 5           | 50               | 3.5            | 0.06              | 0.87     | 0.5      | 58   |
|       |                | 6           | 50               | 3.5            | 0.08              | 0.79     | 0.3      | 44   |
| 6     | Hydrocarbon-based blocking fluid | 7 | 50               | 3.5            | 0.20              | 0.14     | 0.1      | 75   |
|       |                | 8           | 50               | 3.5            | 0.03              | 0.15     | 0.0      | 64   |
| 7     | Gel-forming cement slurry | 9      | 50               | 3.5            | 0.07              | 0.96     | 0.4      | 43   |
|       |                | 10          | 50               | 3.5            | -                 | 0.16     | 0.1      | 71   |
| 8     | Gelling slurry for temporary isolation | 11 | 50               | 3.5            | -                 | 0.34     | 0.2      | 62   |
|       |                | 12          | 50               | 3.5            | 2.70              | 0.69     | 0.4      | 68   |
| 9     | Gelling composition | 13        | 50               | 3.5            | 3.20              | 0.13     | 0.1      | 86   |
|       |                | 14          | 50               | 3.5            | -                 | 0.95     | 0.7      | 75   |
| 10    | Gelling compound | 15         | 50               | 3.5            | -                 | 0.16     | 0.1      | 92   |
|       |                | 16          | 50               | 3.5            | 1.80              | 0.14     | 0.0      | 63   |
| 11    | C HS-1600      | 17          | 50               | 3.5            | 1.60              | 0.15     | 0.0      | 55   |
|       |                | 18          | 50               | 3.5            | 0.15              | 0.30     | 0.2      | 80   |

Figure 1 shows the experimental setup that simulates the process of clogging of the reservoir during well repair.

In order to select the composition for the temporary blocking of the formation that meets the above requirements, as well as to quantify the plugging capacity of the gas reservoir rocks, laboratory studies were conducted. During the experiments, the clogging ability of known compositions of technological
systems was determined. Artificial cement-sand cores with different permeabilities, with a special technology, were used as permeable samples. To exclude chemical clogging, the core material did not contain a swelling substance (clay). Drilling solutions (weighted and thickened), blocking liquids, gel-forming compounds, salt solutions and technical water (table 1) were used as well-known compounds of technological systems.

Residual permeability of the core was determined by the method of [7].

Indicator of the degree of clogging ability of the studied liquids on the core adopted the coefficient of recovery of permeability $\beta$, determined by the formula:

$$\beta = \left( \frac{K_b}{K_o} \right) \cdot 100 \%,$$

where $K_b$ – the coefficient of permeability of the core after its interaction with blocking fluid (after decolmatisation); $K_o$ is the coefficient of initial permeability of the core.

From table 1 it follows that even water for gas reservoirs can be a mechanical plugging. From experience No. 2, it can be seen that with a low initial permeability of the core and exposure to mud, the coefficient $\beta$ is very high and decreases as $K_o$ increases. The formed mud cake has a restraining effect on the penetration of the mud filtrate into the formation. This is explained by the fact that with an increase in $K_o$, the surface tension of the filtrate and water significantly decreases, which facilitates the process of its displacement by gas. However, the situation changes under the influence of highly viscous systems on the core, especially those containing a solid phase [7].

From the experimental data it can be seen that a high degree of clogging ability ensures presence of inert-blocking solutions, which are essentially chemically neutral substances contained in a reservoir and contains a solid phase, which is similar to bentonite when exposed to solutions of thixotropic properties.

Minimizing the damage to reservoir productivity in terms of reducing its natural permeability, which is especially important when operating wells under Abnormal Seam Pressure conditions, allows the use of biopolymers at the microbial level as the basis of working fluids for well repair. The practical value of biopolymers is determined primarily by their ability to sharply change the rheological properties of aqueous systems in low concentrations: increase viscosity, form gels, serves as stabilizers for suspensions and emulsions. These properties have attracted the attention of oil and gas producers, and biopolymers in the last two decades have been tested and applied in the practice of exploration and production drilling, changes in the bottom hole formation capacity, improved efficiency of oil displacement processes, and in recent years also during work over [7].

Biopolymers of the “xanthan” type produced in the West are obtained in the form of a dry powder, which considerably reduces the cost of transportation of the product, since the solution contains 98-99% water in the finished form. At the same time, the “dry product” causes a number of problems: the repeated increase in the cost of production, the need to use toxic substances in the process of isolation and drying to ensure term of containment (expiration), environmental pollution, the need for special equipment for preparing a solution from powder.

For the temporary blocking of the reservoir, we propose a viscoelastic compound (VUR) based on SupraXan biopolymer [8]. The main chain of SupraXan is composed of D-glucose units linked by 1,4 b-glycosidic bonds, and in the branches of the core is a trisaccharide consisting of $\beta$-D-mannose, $\beta$-D-glucuronic acid and $\alpha$-D-mannose. Glucuronic acid residues and acid pyruvic groups impart an anionic character of [5-8] to xanthan molecules. SupraXan molecules in aqueous solutions are prone to self-association and with an increase in the ionic strength of the solution or the concentration of the polysaccharide a gel is formed. The cross-linking reagent in the composition of the solution is TEAT-1.

According to the results of laboratory studies, it is most effective to apply the gel-forming compound without fillers under conditions of low permeability of the reservoir ($\leq 0.1$ mcm$^2$). In order to expand the range of application of the composition for various mining and geological conditions, introduced fillers differ in chemical nature and degree of dispersion. In order to more clearly present the change in the coefficient of core permeability recovery ($\beta$) and the change in core plugging factor ($\gamma$) from the
content of clogging filler, graphs were prepared for the gel-forming compound with fiberglass (figure 2, 3).

![Figure 2](image)

**Figure 2.** Change of core permeability recovery coefficient ($\beta$) from the content of clogging filler ($C$).

The usage of the proposed composition is optimal for cores with a permeability of 0.5–0.9 mcm$^2$ at a fiber concentration in the gel of 0.25–0.40 % of total mass. The thin inert fiber under the influence of pressure reliably blocks the “cracks” of the test core sample. As part of the solution, it is located perpendicular to the core crack and forms a solid shield on the sample surface due to damped filtration. Due to the minimal penetration of the gel into the core (1.0–3.0 mm), the sample was released at a pressure three times lower than the repression pressure.

![Figure 3](image)

**Figure 3.** Change in core plugging rate ($\gamma$) from the content of clogging filler ($C$).

Temporarily isolating the core with a permeability of 1 mcm$^2$ is effectively a gel system with cord fiber. For the core permeability from 0.2 to 0.54 mcm$^2$, the best performance was obtained when processing the cross-linked gel system with basalt fiber filler.
In real conditions, the composition for temporary blocking will interact with the rock. Therefore, additional studies of the adhesive properties of the composition on artificial rock samples were carried out.

In the course of the experiments with the compositions under investigation, gas was returned from the reciprocating gas to the syringe with air supply of 1–2 cm$^3$. An air bubble was formed inside the composition, which was retained within the system without rising to the surface (Figure 4). This indicates a sufficient strength of the gel structure during its interaction with the rock, which allows concluding that the adhesive and gas-blocking ability is high.

![Figure 4. Test of holding capacity of the gel-forming composition](image)

We also offer compositions of process fluids based on biopolymer (Saraksan, SupraXan), which can be used for flushing sand plugs, sidetracking and well completion. Biopolymer liquids have reduced filtration properties and pronounced pseudoplastic, and the content of antifreeze in the compositions allows the use of these liquids at negative temperatures in winter. The main physico-chemical properties and structural and rheological parameters of process fluids are presented in table 2.

Biopolymer fluids have improved structural and rheological properties that ensure their increased retention and transport capacity. The latter are characterized by the nonlinearity coefficient $n$. The smaller the $n$, the more the solution exhibits pseudoplastic properties. This means that viscosity decreases with increasing relative shear rates and, conversely, viscosity increases with decreasing relative shear rates. Reducing the constant $n$ allows you to improve the removal of rock and cleaning of the well due to the alignment (flattening) of the velocity profile of fluid flow in the annular space.

| Indicator                                | Value       |
|------------------------------------------|-------------|
| **Biopolymer liquid without antifreeze** |             |
| Density, kg/m$^3$                        | 600 ÷ 842   |
| Filtration, cm$^3$/30 min                | 2.0 ÷ 4.0   |
| Plastic Viscosity, mPa·s                 | 13 ÷ 28     |
| Dynamic shear stress, dPa                | 144 ÷ 373   |
| Static shear stress for 1 and 10 min, dPa| 29 ÷ 124 / 34 ÷ 168 |
| Nonlinearity coefficient, $n$            | 0.30 ÷ 0.40 |
| Freezing point, °C                       | -3 ÷ -5     |
| **Biopolymer liquid with antifreeze**    |             |
| Density, kg/m$^3$                        | 630 ÷ 990   |
| Filtration, m                            | 2.0 ÷ 4.8   |
| Plastic Viscosity, mPa·s                 | 16 ÷ 31     |
| Dynamic shear stress, dPa                | 129 ÷ 254   |
| Static shear stress for 1 and 10 min, dPa| 34 ÷ 91 / 34 ÷ 115 |
| Nonlinearity coefficient, $n$            | 0.37 ÷ 0.47 |
| Freezing point, °C                       | -12 ÷ -39   |
Compared with the water-soluble synthetic polymers traditionally used in gas production, in particular, PAA, biopolymers have a number of significant advantages, including such that allow their use in very harsh environments where the use of synthetic polymers is ineffective.

The cost of biopolymer systems is higher than conventional process fluids containing synthetic polymers. Despite the high cost of biopolymers, their use is beneficial, since the negative impact of biopolymer fluids on the reservoir is minimized, and the time spent on developing wells decreases after repairs are performed using them. By virtue of these advantages, these systems are effective, and they have no alternative under certain conditions.

The use of biopolymers, which are products of the life of microorganisms, in process fluids for wells with high temperatures (over 100 °C) are not found in the field practice of oil and gas producing enterprises, since the effectiveness of microbial biopolymers is generally limited to temperatures of 60–80 °C. In this regard, we can conclude about the feasibility of using biopolymers in the compositions of process fluids with weighting additives for the overhaul of wells in the conditions of ASP (abnormal seam pressure) with compliance of the specified temperature limits of usage.

For the use of biopolymers of microbial origin in the overhaul of wells with ASP at higher temperatures, they need to be adjusted during the production process or the development of multicomponent biopolymer fluids characterized by increased heat resistance.

4. Conclusion
1. The analysis of modern process fluids used for repair and restoration work was carried out, the results of which substantiated the effectiveness of the use of solutions on a biopolymer basis.
2. The requirements for process fluids for temporary blocking of the formation were determined.
3. The proposed composition for the temporary blocking of the reservoir in the form of a polymer-containing gel with clogging fillers. It has been tested for gas holding capacity and contact strength (adhesion) with rock and metal. With the help of experimental installations, the coefficient of permeability recovery and the blocking rate of the core were determined.
4. The proposed composition of process fluids based on biopolymer (Saraksan, SupraXan), which can be used for flushing sand plugs, sidetracking and well development. Biopolymer liquids have reduced filtration properties and pronounced pseudoplastic, and the content of antifreeze in the compositions allows using these liquids at negative temperatures in winter.

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