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DETERMINATION OF THE DEPENDENCE OF THE FILTRATION PROPERTIES OF A BIOPOLYMER SYSTEM ON PRESSURE, TEMPERATURE AND CONCENTRATION OF COMPONENTS

The object of study is the biopolymer system "X", which is used as a clay-free drilling fluid for development of productive horizons. Biopolymer system "X" is a clay-free drilling fluid for drilling directional and horizontal wells, development of productive horizons under high pressures and temperatures.

A distinctive feature of the biopolymer system is a high level of mineralization, increased heat resistance and high density, which significantly expands the scope of clay-free muds.

At the same time, this system has a number of significant advantages:

– high level of mineralization;

– increased heat resistance (operable up to 150 °C);

– high density, which expands the scope of application;

– provides a higher coefficient of recovery of reservoir permeability compared to traditional weighted solutions;

– low content of colloidal particles, which reduces the risk of deterioration of reservoir performance;

– ability to control filtration properties at high temperatures and pressures.

The following disadvantages can be identified based on the research:

1. Significant increase in the filtration rate with increasing temperature (nonlinear dependence with a correlation coefficient of 0.773).

2. The need to maintain a constant concentration of potassium chloride (~3 %) to ensure the development quality of productive formations.

3. Difficulty in controlling the properties due to the need to accurately select the concentrations of various components (sodium chloride and organomineral colmatant).

The optimal ratio of components to ensure the stability of the system at temperatures up to 150 °C was obtained: sodium chloride concentration 15–20 %, stabilizer 0.75–1 %. This is due to the fact that the proposed composition has a number of features of synergistic interaction of the components, in particular the formation of stable complexes between biopolymers and sodium ions, which prevents the thermal destruction of polymer chains at high temperatures. At the same time, the stabilizer forms an additional protective layer around the polymer molecules, ensuring their resistance to oxidation and hydrolysis under high pressure of up to 7 MPa.

The obtained research results indicate the possibility of effective use of the biopolymer system at high temperatures and pressures due to the thermostabilizing effect of sodium chloride and organo-mineral colmatant.

Keywords: *biopolymer system, rheological properties, biopolymer stability, formulation optimization, high-temperature stability.*

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1. Introduction

Recently, clay-free drilling fluids have been increasingly used to develop productive horizons, which ensure the highest level of preservation of their reservoir properties [1]. This is largely due to the low content of colloidal particles, the penetration of which into the pore space of reservoirs is one of the main factors in the deterioration of their productive characteristics [2]. At the same time, if recently the use of clay-free systems was limited to zones of abnormally low or hydrostatic pressures, now there is an increasing need for their implementation in deep wells, with high reservoir pressures and temperatures [3]. It is possible to increase the density of clay-free drilling fluids by treating them with water-soluble salts [4]. With this method of weighting, it is possible to avoid a violation of the ratio between colloidal and coarse-dispersed solid phases and thereby eliminate the main cause of the increase in bottomhole filtration [5]. In addition, due to the increase in the overall mineralization of the medium, the inhibitory properties of the clay-free system and the thermal stability of biopolymer reagents increase [6]. Clay-free drilling fluids, weighted with water-soluble salts, retain all the positive characteristics inherent in traditional biopolymer

systems: low surface filtration, high level of pseudoplasticity [7], instant thixotropy [8].

The successful use of biopolymer clay-free systems in drilling inclined and horizontal wells, and in developing productive reservoirs with abnormally low reservoir pressure indicated high prospects for their further improvement [9].

At the same time, the scope of application of clay-free systems was limited by the low thermal stability of polysaccharide reagents, which are the basis for obtaining a polymer thixotropic structure. In the geological conditions of Ukraine, the temperature stability limit of biopolymer systems at 110–120 °C excludes the possibility of their use in DDD (Dnipro-Donetsk Depression) deposits with a depth of more than 3500–4000 m.

The use of weighted drilling fluids on a clay or polymer clay basis is associated with difficulties due to the increase in structural-mechanical and rheological characteristics, especially at high temperatures [10]. This leads to excessive dynamic loads on permeable formations during circulation recovery, reduces the upper limit of the solution weighting, complicates hydrodynamic studies, leads to excess reagent consumption and environmental pollution.

Therefore, *the aim of research* is to determine the patterns of change in the filtration properties of the biopolymer system depending on temperature, pressure and component concentrations to optimize its composition.

2. Materials and Methods

The biopolymer system "X" has undergone a number of studies, in particular, studies of rheological, structural-mechanical and filtration properties.

The technological properties of the biopolymer system "X" at temperatures up to 150 °C were studied. The components of the formulation are the complex reagent "X" for regulating the structural-mechanical, rheological and filtration properties, as well as inhibitors (sodium and potassium chloride) and filler [10]. The concentration of potassium chloride in the system is maintained at a constant level (~3 %), which is the minimum necessary to ensure the quality of the developing productive layers and the stability of rocks. The components of the biopolymer system (sodium chloride, organo-mineral colmatant heat stabilizer) increase its heat resistance.

Table 1 shows some information on the technological properties of the biopolymer system "X" for various combinations of concentrations of sodium chloride and organo-mineral colmatant heat stabilizer. Measurements were made after thermostating the drilling fluid for 2 hours at a temperature of 85 °C. In particular, increasing the composition of the studied reagents (thermal stabilizer) increases the viscous properties, reduces (sodium chloride, thermal stabilizer) filtration indicators on the BM-6 device (at room temperature 25 °C) and Filterpress HPHT (China) (at a pressure drop of 5.0 MPa and a temperature of 140 °C). The latter shows the thermostabilizing effect of the reagents used.

Table 1

Technological properties of the biopolymer system "X"

Drilling mud composition	Density, kg/m^3	Conditional viscosity T_{100}, s	$CHC_{1/10}$, Pa	Filtration, cm^3/30 min	
				BM-6	HPHT, 140 °C
"X"	1150	15	4.8/5.7	4.0	22
"X"+0.25 % stabilizer	1150	18	4.3/4.8	3.5	16
"X"+1 % stabilizer	1150	22	6.2/6.7	3.5	14
"X"+5 % NaCl	1180	10	3.8/4.3	3.0	14
"X"+25 % NaCl	1280	16	5.2/5.7	3.0	18
"X"+5 % NaCl+0.25 % stabilizer	1180	14	4.3/4.8	3.0	13
"X"+10 % NaCl+1 % stabilizer	1220	21	4.8/5.7	2.5	10
"X"+25 % NaCl+1 % stabilizer	1280	17	5.7/6.2	3.0	12

The experimental plan for studying the rheological, structural-mechanical and filtration properties of the biopolymer system "X" under conditions of high pressures and temperatures is given in Table 2.

Table 2

Experimental plan for studying the biopolymer system "X" under conditions of high temperatures

Experiment	Sodium chloride, %	Stabilizer, %	Temperature T, °C	Pressure drop Δp, MPa
1	20	0.5	150	3
2	20	0.75	130	7
3	15	0.5	50	5
4	10	1	150	4
5	10	0.25	100	7
6	15	1	130	6
7	15	1.5	70	3
8	25	0.5	70	4
9	20	1.5	100	6
10	25	1.5	130	5
11	25	0.25	50	6
12	10	1.5	50	7
13	15	0.25	150	5
14	10	0.5	130	4
15	5	0.25	130	3
16	10	0.75	70	5
17	25	1	100	5
18	15	0.75	100	4
19	25	0.75	150	6
20	20	0.25	70	6
21	20	1	50	4
22	5	1	70	7
23	5	0.75	50	3
24	5	0.5	100	3
25	5	1.5	150	7

The research design has the following experimental factors:

– *Sodium chloride concentration* (%) – varies from 5 % to 25 % in 5 % increments. This allows to investigate the effect of salinity on the properties of the biopolymer system.

– *Stabilizer concentration* (%) – levels: 0.25 %, 0.5 %, 0.75 %, 1 %, 1.5 %. The stabilizer plays an important role in maintaining the structural integrity of the biopolymer system at high temperatures.

– *Temperature* (°C) – values of 50 °C, 70 °C, 100 °C, 130 °C and 150 °C are investigated. This range allows to assess the thermal stability of the biopolymer system from moderate to extreme temperatures.

– *Pressure drop* (MPa) – varies from 3 to 7 MPa. This parameter is a dependent variable that is measured as the response of the system to different experimental conditions.

The plan demonstrates a balanced distribution of factors – each level of each factor occurs the same number of times (5 experiments each), which provides a uniform statistical weight for all studied conditions.

3. Results and Discussion

One of the most important requirements in the technology of drilling deep wells in conditions of high temperatures and pressures is the control and management of the filtration properties of drilling fluids. The penetration of the drilling fluid filtrate

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worsens the collector properties of productive layers, which is the cause of drilling complications.

Studies of static filtration of the biopolymer system "X" were carried out on the Filter press HPHT device (Fig. 1) with the aim of predicting its change depending on the temperature T, the concentrations of reagents for thermal stabilization of sodium chloride and the organo-mineral colmatant of the thermal stabilizer, and the pressure drop Δp.

Fig. 1. HPHT filter press

The studies used a Latin experimental design for four variables: temperature $T=(50, 70, 100, 130, 150)$ °C; sodium chloride content $c_c=(5, 10, 15, 20, 25)$ %; organo-mineral colmatant stabilizer content $c_a=(0.25, 0.50, 0.75, 1.00, 1.50)$ %; pressure drop $\Delta p=(3, 4, 5, 6, 7)$ MPa.

The studies were conducted on a standard paper filter with a constant pressure of 0.7 MPa on the lower valve of the device to prevent evaporation of the filtrate at high temperatures.

To process the measurement results, regression models $\Phi(T, c_c, c_a, \Delta p)$ in the form of second-order polynomials were used:

$$\Phi(T, c_c, c_a, \Delta p)=B^T\cdot b(T, c_c, c_a, \Delta p), \quad (1)$$

where $b(T, c_c, c_a, \Delta p)$ – the vector of basis functions of polynomial models (Table 3).

The estimates of the parameter vector $\hat{B}$ in (1) and the regression model $\hat{\varepsilon}$ for the filtration index Φ are constructed in the class E of various combinations of basis functions from the condition of minimum variance adequacy:

$$\min\left\{S_\varepsilon^2=\frac{1}{n-r_\varepsilon}\sum_{i=1}^{n}\left[B_i\ b(T_i, c_{ci}, c_{ai}, \Delta p_i)-\Phi_i\right]^2\right\}\Rightarrow$$
$$\Rightarrow\left\{\hat{B}, \hat{\varepsilon}\right\},\ \varepsilon\in E, \quad (2)$$

where r_ε – the number of estimated parameters in the models (1); T_i, c_{ci}, c_{ai}, Δp_i – experimental design data (Table 3); Φ_i – results of filtration index measurements.

In the process of laboratory research of the biopolymer system "X", it was noted that a statistically significant nonlinear trend of an increase in the filtration index from temperature (correlation coefficient $r_{\Phi T}=0.773$) is characteristic. An increase in the concentrations of sodium chloride (correlation coefficient $r_{\Phi c_c}=-0.077$) and the filler of the thermal stabilizer (correlation coefficient $r_{\Phi c_a}=-0.263$) has almost no statistically significant effect on the nature of the change in the filtration index with temperature, which confirms their thermal stabilizing effect on the biopolymer system "X". At high concentrations of sodium chloride and the filler of the thermal stabilizer, a decrease in the degree of influence of temperature on the filtration index is observed. A statistically insignificant effect of the pressure drop Δp on the dependence of the filtration index on temperature (correlation coefficient $r_{\Phi\Delta p}=0.252$) was also noted.

Table 3

Parameters of the equations of state for the filtration performance of the biopolymer system "X"

Basis functions b_i	Model parameters (1)	Values of model B_i parameters (1) at r_ε						
		5	6	10	11	15	18	19
1	B_1	2.640	12.784	20.022	23.313	23.925	7.387	8.704
T	B_2	0.077	–0.158	–0.211	–0.216	–0.217	–0.126	–0.124
c_c	B_3	–0.054	0.054	–0.548	–1.211	–1.717	–1.425	–1.234
c_a	B_4	–2.690	–2.690	–9.662	–11.480	–14.123	–10.535	–13.822
Δp	B_5	0.688	0.688	0.610	0.709	1.813	7.083	7.025
Tc_c	$B_6\cdot10^3$	–	–	5.810	7.171	9.534	12.014	9.353
Tc_a	B_7	–	–	0.077	0.089	0.112	0.149	0.169
$T\Delta p$	B_8	–	–	–	–	–	–0.031	–0.035
c_cc_a	B_9	–	–	0.402	0.677	0.809	1.343	1.260
$c_c\Delta p$	B_{10}	–	–	–	–	0.047	–0.071	–0.118
$c_a\Delta p$	B_{11}	–	–	–	–	–0.319	–2.118	–1.988
Tc_cc_a	$B_{12}\cdot10^3$	–	–	–4.823	–7.243	–9.611	–25.107	–24.147
$Tc_a\Delta p$	$B_{13}\cdot10^3$	–	–	–	–	–	–	3.401
$c_cc_a\Delta p$	B_{14}	–	–	–	–	–	–0.103	–0.024
$Tc_cc_a\Delta p$	$B_{15}\cdot10^3$	–	–	–	–	–	2.844	2.361
T^2	$B_{16}\cdot10^3$	–	1.174	0.962	0.970	0.843	9.170	0.918
c_c^2	B_{17}	–	–	–	0.017	0.021	0.025	0.024
c_a^2	B_{18}	–	–	–	–	2.168	4.244	4.672
Δp^2	B_{19}	–	–	–	–	–0.152	–0.261	0.233
S_ε^2 (ml/30 min)^2		4.367	2.830	2.871	2.370	2.752	3.038	3.496

Fig. 2 shows the characteristic dependences of the filtration index Φ on the concentrations of sodium chloride and stabilizer filler in the studied range of their changes for fixed temperature and pressure drop. For sodium chloride, the dependence $\Phi(c_c)$ under certain conditions has a minimum (Fig. 2, *a*), the concentration c_{ci}^* of which in the studied range is estimated from:

$$c_c^* = \begin{cases} \left(B_3 + B_6 T + B_9 c_a + B_{12} T c_a\right) / \left(-2B_{17}\right), \text{ if } c_c^* \in \left]c_c^{\min}, c_c^{\max}\right[; \\ c_c^{\min}, \text{ if } \Phi\left(c_c^{\min}\right) < \Phi\left(c_c^{\max}\right); \\ c_c^{\max}, \text{ otherwise,} \end{cases} \quad (3)$$

where $c_c^{\min}$, $c_c^{\max}$ – the lower and upper limits of the change in concentrations in the experimental plan. For the filler of the thermal stabilizer, the dependence $\Phi(c_a)$ is linear (Fig. 2, *b*).

Analysis of the results of studies of statistical filtration of the biopolymer system "X" confirms the mechanism of thermostabilizing effect of sodium chloride and organo-mineral colmatant of the thermal stabilizer. This mechanism is associated with an increase in total mineralization and intensification of gelation processes, as well as thickening of the filtration crust and an increase in rheological properties.

Based on studies of static filtration of the biopolymer system, the possibility of its regulation at temperatures up to 150 °C and pressure drops up to 7 MPa was established by choosing the concentrations of sodium chloride and filler of the stabilizer. The regression dependences of the filtration index on the state parameters in the temperature range of 50–150 °C with concentrations of sodium chloride additives of 5–25 % and organo-mineral colmatant thermal stabilizer of 0.25–1.5 % were obtained.

The study of regression models for the filtration index allows to more reasonably build a system of restrictions on the concentration of reagents taking into account thermobaric conditions [3] for specific layers of the well section.

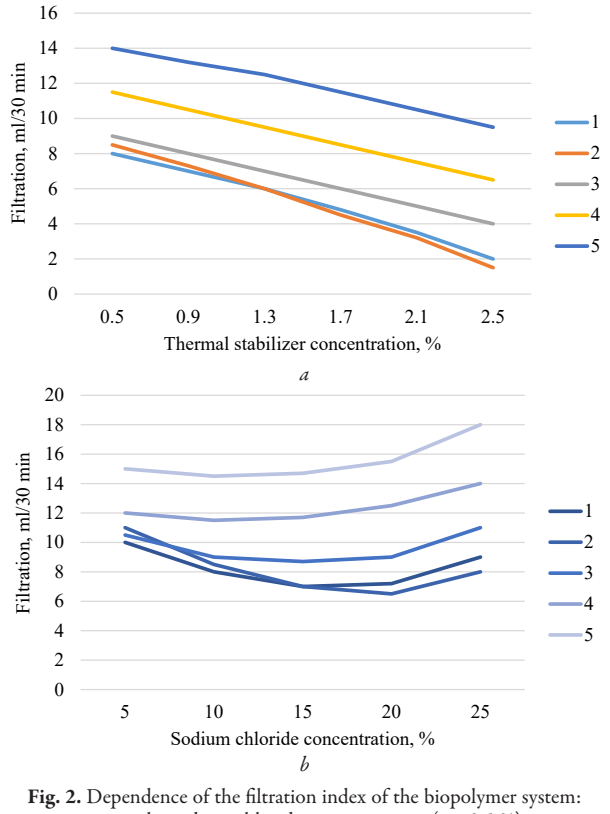

Fig. 2. Dependence of the filtration index of the biopolymer system: *a* – on the sodium chloride concentrations (c_a=0.5 %); *b* – thermal stabilizer filler (c_c=15 %), where the pressure drop (Δp=3 MPa) and temperature (1 – T=50 °C; 2 – T=70 °C; 3 – T=100 °C; 4 – T=130 °C; 5 – T=150 °C)

Fig. 2 shows graphs of the dependence of the change in filtration properties depending on the concentrations of sodium chloride, colmatant thermal stabilizer, pressure drop and temperature.

Based on the studies of static filtration of the biopolymer system, the possibility of its regulation at temperatures up to 150 °C and pressure drops up to 7 MPa was established by choosing the concentrations of sodium chloride and filler of the thermal stabilizer. Regression dependences of the filtration index on the state parameters in the temperature range of 50–150 °C with concentrations of sodium chloride additives of 5–25 % and organo-mineral colmatant of 0.25–1.5 %.

The practical significance lies in obtaining regression dependences of the filtration index on the parameters of the system state, which allows reasonably selecting reagent concentrations taking into account the thermobaric conditions of specific formations.

There are certain limitations:

– temperature range up to 150 °C;
– pressure drops up to 7 MPa;
– sodium chloride concentrations 5–25 %;
– organo-mineral colmatant concentrations 0.25–1.5 %.

Martial law also had an impact on the research results, because the difficulty lies in importing the necessary equipment and reagents.

In the future, it is advisable to:

1. Expand the range of studied temperatures and pressures.
2. Investigate the influence of other components on filtration properties.
3. Optimize the composition of the system for different geological conditions.

4. Conclusions

The mechanism of the thermostabilizing effect of sodium chloride and organo-mineral colmatant has been confirmed.

The possibility of regulating the filtration properties of the system at temperatures up to 150 °C and pressure drops up to 7 MPa has been established.

Regression dependences of the filtration index on the state parameters in the temperature range of 50–150 °C with concentrations of sodium chloride additives of 5–25 % and organo-mineral colmatant of 0.25–1.5 % have been obtained.

It has been shown that increasing the concentrations of sodium chloride and the thermal stabilizer filler reduces the effect of temperature on the filtration index.

A method for the justified selection of reagent concentrations taking into account thermobaric conditions has been developed.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

The manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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References

1. Luban, Yu. V., Kuntsiak, Ya. V., Luban, S. V., Bileka, O. A. et al. (2008). "BIO-KAR" – bezghlynysta promyvalna ridyna dlia burinnia pokhylo-skerovanykh i horyzontalnykh sverdlovyn ta rozkryttia produktyvnykh horyzontiv. *Naftova i hazova promyslovist, 4*, 18–21.
2. Mysliuk, M. A., Salyzhyn, Yu. M. (2007). Systema vyboru optymalnykh retseptur obrobky burovykh rozchyniv. *Naftova i hazova promyslovist, 5,* 25–28.
3. Rubel, V., Slichenko, R. (2024). Selection of the optimal formulation of the biopolymer system for the stimulation of productive formations. *Technology Audit and Production Reserves, 5 (1 (79)),* 57–61. https://doi.org/10.15587/2706-5448.2024.314230
4. Luban, Yu. V., Luban, S. V., Dudzych, V. V., Boiko, A. H., Semeniuk, V. H. (2013). Zastosuvannia bezghlynystykh promyvalnykh ridyn v umovakh vysokykh plastovykh tyskiv i temperatur. *Naftohazova haluz Ukrainy, 2,* 18–22.
5. Koroviaka, Ye. A., Stavychnyi, Ye. M., Martsynkiv, O. B., Ihnatov, A. O., Yavorskyi, A. V. (2024). Research on occurrence features and ways to improve the quality of productive hydrocarbon horizons demarcation. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, 3,* 5–11. https://doi.org/10.33271/nvngu/2024-3/005
6. Liu, T., Leusheva, E., Morenov, V., Li, L., Jiang, G., Fang, C. et al. (2020). Influence of Polymer Reagents in the Drilling Fluids on the Efficiency of Deviated and Horizontal Wells Drilling. *Energies, 13 (18),* 4704. https://doi.org/10.3390/en13184704
7. Polutrenko, M. S., Bogoslavets, V. V., Voloshyn, Yu. D. (2021). Study of surface and rheological properties of clayless biopolymer drilling mud treated with M-1 surfactants. *Oil and Gas Power Engineering, 1 (35),* 91–97. https://doi.org/10.31471/1993-9868-2021-1(35)-91-97
8. Boyer, C., Figueiredo, L., Pace, R., Lesoeur, J., Rouillon, T., Visage, C. L. et al. (2018). Laponite nanoparticle-associated silated hydroxypropylmethyl cellulose as an injectable reinforced interpenetrating network hydrogel for cartilage tissue engineering. *Acta Biomaterialia, 65,* 112–122. https://doi.org/10.1016/j.actbio.2017.11.027
9. Gu, M., Fan, S., Zhou, G., Ma, K., Yao, X., Zhang, Y. (2022). Effects of dynamic mechanical stimulations on the regeneration of in vitro and in vivo cartilage tissue based on silk fibroin scaffold. *Composites Part B: Engineering, 235,* 109764. https://doi.org/10.1016/j.compositesb.2022.109764
10. Salati, M. A., Khazai, J., Tahmuri, A. M., Samadi, A., Taghizadeh, A., Taghizadeh, M. et al. (2020). Agarose-Based Biomaterials: Opportunities and Challenges in Cartilage Tissue Engineering. *Polymers, 12 (5),* 1150. https://doi.org/10.3390/polym12051150

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