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## Testing of preformed particles polymer gel technology on core filtration models to limit water inflows

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In order to reduce watering of wells and equalize their injectivity profiles, the prospects of introducing PPG technology in Russian fields are considered, in which preformed particles polymer gel are pumped into the injection well. These particles, being a supersorbent based on polyacrylamide, absorb water, become elastic, which allows them to shrink and tear in narrow filtration channels. When the polymer is filtered along permeable layers saturated with water, polymer particles accumulate in waterlogged intervals and thus they form a polymer plug, which redistributes the filtration flows and increases the coverage of the formation by the process of oil displacement.

More than 4000 downhole operations have been carried out in the fields of China and the USA using PPG technology by now. In domestic fields in Western Siberia, there is limited experience in applying a similar technology in high-temperature formations with low mineralization of formation water. Due to the absence of hydrolytic processes in polyacrylamide, well-known domestic compositions are not applicable due to the low absorption capacity in the conditions of low-temperature deposits with increased mineralization of formation water.

The authors synthesized a polymer based on polyacrylamide by block polymerization, which allows to obtain a high absorption capacity, including for low-temperature formations with high mineralization of formation water, which is typical for Perm Territory fields.

Filtration experiments were carried out on core models with the composition developed by the authors, this composition focused on low formation temperatures and high mineralization of formation water. As a result of the experiments, it was found that the swollen particles of the gel are able to pass into fractures with a diameter less than their own size at least 20 times. With a significant increase in the viscosity of the dispersion medium, the stability of the suspension increases. Particles of polymer gel have the necessary strength for injection in the field conditions. The fracture permeability during polymer injection decreases by several times and becomes comparable with the permeability of pore collectors.

**Key words:** watering of producing wells; injectivity profile; injection wells; superabsorbent; preformed polymer gel; polyacrylamide; filtration tests; permeability; injection pressure

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**Introduction.** Most of the oil deposits of the Perm Krai are in the late stages of development, as a result of which geological and technical operations (GTO) are widely used for them to reduce watering well production. The GTO performed at the production well stock are mainly associated with casing leakage, which is solved by the use of quick-setting cement materials, polymer swelling nets, viscoelastic compositions, etc. [4]. In recent years, according to oil and gas companies of the Perm Krai, the efficiency of water-proofing operations in wells does not exceed 50 % [1].

The effectiveness of waterflooding methods is reduced due to water filtration in already washed zones for deposits with high viscosity oils and heterogeneous geological structure. For such deposits, intensive flooding begins at the third stage of development [7]. To solve this problem, the impact on the formation, as a rule, is carried out through injection wells. At the final stages of development, the task of redistributing filtration flows is most often solved by using various chemicals.

In Russia, the usual water-soluble [8] or polyacrylamide (PAA) preformed with polyvalent metal ions has found the greatest use for leveling injection well capacity profiles. PAA can signifi-



cantly increase the viscosity of water even at low concentrations, increasing the coverage of heterogeneous formations by water flooding. Water-soluble PAA loses its viscosity at a high shear rate, and PAA preformed by polyvalent metal ions in the formation changes its consistency due to the different speed of movement of structure-forming components in the formation. This phenomenon can cause blocking of low-permeability undeveloped intervals [11, 15]. In addition, a technological feature of the water-soluble polymers injection is the need to eliminate the processes of their oxidation when dissolved in water. Accordingly, the installation of PAA injection provides for the formation of a nitrogen atmosphere above the mixing tank, which requires additional financial costs.

In this regard, watering reduction technologies should be focused on the search for new effective compounds. Authors consider promising methods that not only increase the viscosity of water, are capable of colmatizing the highly permeable channels through which the formations are watered.

**Short review of the technology.** Over the past two decades, a PPG (preformed particle gel) technology has been effectively applied to reduce watering in world practice. The essence of the technology is the pumping into an injection well of a suspension based on particles of a preformed acrylamide-based polymer. The absorbent particles absorb water, while increasing in volume and becoming elastic, which allows them to shrink and tear in narrow filter channels.

In the late stages of development, in the process of developing a deposit, the characteristics of near-well zones in production and injection wells deteriorate (colmatizing, deposition of salts and paraffins, etc.) [6]. With this in mind, the composition of PPG is required to freely pass the gel through the bottomhole formation zone (BFZ). Then the polymer moves mainly along the most permeable flooded interlayers of the remote formation zone (RFZ). Although permeability in the RFZ is generally higher than in the BFZ, due to the decrease in injection pressure, the speed of polymer movement is significantly reduced. As a result, a polymer plug forms in the most permeable intervals. The filtration flows are redistributed into low-permeability layers, which contributes to an increase in the coverage of the formation with the process of oil displacement.

Since the 2000s, PPG technology has been successfully used to reduce formation watering in China and the USA, in 2013 more than 4,000 well operations were carried out [9, 11]. At domestic deposits, mainly in Western Siberia, by now, there is also a limited experience in the application of preformed polymer flooding technologies. These include the “Temposcrin” polymer-gel system [3], “RITIN-10” reagents [5] and “AK-639” reagents [2]. These technologies are applicable in conditions of high-temperature formations with low mineralization of produced water. Under low temperature deposit conditions, due to the absence of hydrolytic processes in the polyacrylamide, these compositions show a significantly lower degree of swellability (absorption capacity). Additionally, the swelling process is inhibited by increased salt content in the formation water. So, the use of the known domestic technologies [2, 3, 5] is not effective for deposits of Perm Krai where formation temperatures are 25-30 °C, and mineralization – 240-260 g/l.

Adaptation of PPG technology requires independent manufacture of superabsorbent and production of effective formulations in specific geological and technological conditions. For example, for fields in the Volga-Ural oil and gas province, when developing a polymer formulation, it is important to take into account low formation temperatures and high mineralization of formation water. The development of domestic formulations of PPG technology for the oil industry is an important element in the development of import substitution and environmental management strategies.

**Polymer characterization.** The authors are currently conducting research on the selection of the optimal polymer formulation for the deposits of Perm region. A polymer based on polyacrylamide preformed by covalent polar bonds is synthesized by block polymerization. The obtained polymer sample was crushed and classified into three main fractions with particle size distribution in the dry state: less than 250 μm; 250-500 μm; 500-1000 μm. Figure 1 shows a photo of 1 g of the synthesized polymer powder before and after two hours of contact with salt water (20 % NaCl solution).

The increase in absorption capacity allows the polymer to obtain the necessary mechanical characteristics, making it more elastic, which is the condition for its injection into the formation. According to calculations by the method of [10], the absorption capacity of 1 g of polymer in a 20 % NaCl solution with a density of  $1.145 \text{ g/cm}^3$  averages 38-42 g of water. Figure 2 shows a graph of the change in the absorption capacity of the synthesized polymer during the day. The authors conducted comparative tests to determine the absorption capacity of the developed polymer with foreign analogues. Under identical experimental conditions, the sample synthesized by the authors showed an absorption capacity of at least two times higher than that of analogues. The calculated absorption capacity of the comparison polymers by the method of [10] in a 20 % NaCl solution is noticeably lower and ranges from 3 to 23 g.

**Methodology.** In the experiments we used suspensions with a particle concentration of 1000 ppm (0.1 % by weight) based on a fraction of 250-500  $\mu\text{m}$  of dry powder and a 20 % solution of NaCl. The tests were carried out on the UIK-5VG installation on a core with a through fracture. While planning the experiments, a rock permeability formation model was taken that comprehensively takes into account the rigid (in pores) and soft (in fractures) porosity structure [12-14]. On the extracted core sample (30  $\times$  30 mm) with matrix permeability of less than  $0.001 \mu\text{m}^2$  and natural fracture with permeability of about  $1 \mu\text{m}^2$  were simulated in experiments (Fig.3).

The core sample was located in a coreholder where test conditions were created (temperature 25 °C, pressure of hydrocompression of 80 atm). The direction of filtration corresponded to the conditions of the injection well, i.e. fluid and chemical injection were carried out in one direction, simulating the filtration from the well into the formation. Opening of the crack was ensured by installing in its cross section along the side surface of the sample strip of filter paper with a width of 0.55 cm. The required permeability of the fracture specimen was achieved by adjusting the compression pressure during the test. In all experiments in core models, comparable openings  $W$  (from 65 to 90  $\mu\text{m}$ ) and permeability  $k_{fr}$  (from 0.8 to  $2 \mu\text{m}^2$ ) of fractures were achieved.

The results of filtration tests on the initial fractured cores and after injection of polymer suspensions:

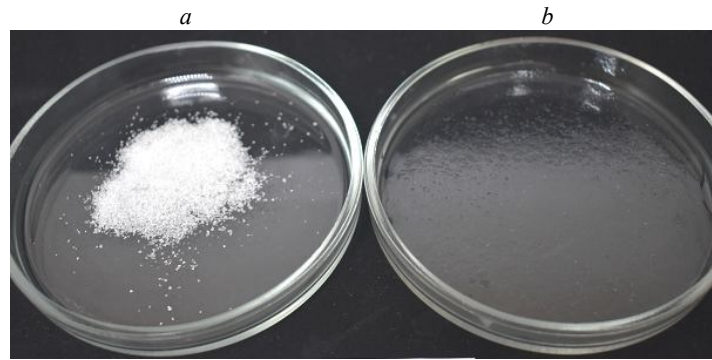


Fig.1. Type of polymer in dry condition (a) and after contact with salt water (b)

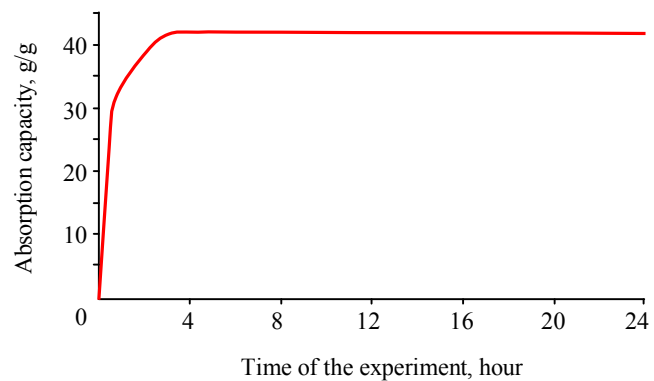


Fig.2. Change in the absorption capacity of the polymer during the day (fraction 0.5-1 mm) in a 20 % NaCl solution



Fig.3. Images of the ends of the core sample from the side of the well (a) and from the side of the reservoir (b) with a natural fracture

Experiment No.	$\mu$ , mPa·s	$W$ , $\mu\text{m}$	$k_{fr}$ , $\mu\text{m}^2$	$k_{PPG}$ , $\mu\text{m}^2$	$P_{max}$ , atm
1	1.5	78.7	1.357	0.081	7.8
2	15.0	65.8	0.791	0.015	7.8
3	37.0	89.7	2.005	0.120	4.0

After preparation, the suspension was held for two hours to achieve maximum absorption capacity and then pumped into the core at a rate of 1 cm<sup>3</sup>/min. After flushing the end from the injection side, the permeability of the core with a fracture colmatized with polymer was determined ( $k_{PPG}$ ). Fig.4 shows graphs of pressure changes during the injection of a polymer suspension, which was calculated as the pressure difference at the inlet and outlet ends of the core sample.

**Results and discussion.** At the first stage as a model of formation water we used water solution of sodium chloride with a density of 1.145 g/cm<sup>3</sup> and viscosity  $\mu = 1.5$  mPa·s. As a result of the filtration test, it was found that the swollen polymer actually enters the fractured space and colmates it. However, Fig.4, *a* shows that the pressure drop for the reagent with  $\mu = 1.5$  mPa·s up to 75 % of the polymer amount (90 out of 120 cm<sup>3</sup>) does not exceed 0.1 atm. This is due to the polymer sedimentation at the bottom of the cylinder and the free filtration of the solution along the fracture without the participation of the polymer. After pumping a 90 % solution (at a flow rate of 108 cm<sup>3</sup>), the sedimentized polymer begins to pump and colmate the fracture. This is reflected by a sharp jump in injection pressure – up to 7.8 atm. It is obvious that these results cannot be considered satisfactory.

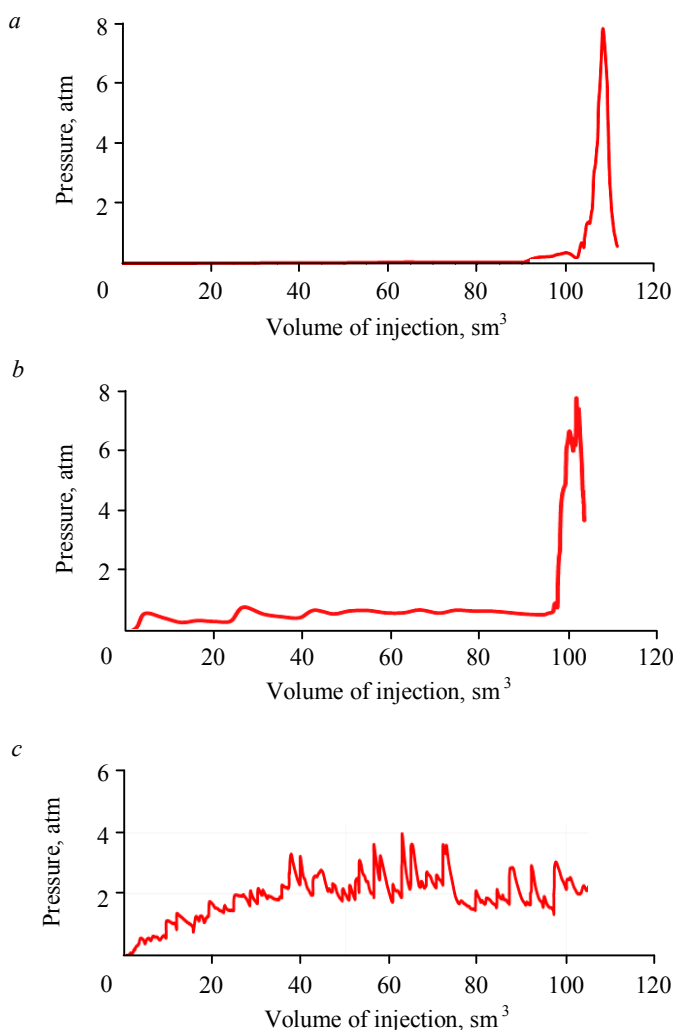


Fig.4. Dynamics of pressure drop during injection of a polymer suspension with viscosities 1,5 mPa·s (*a*); 15 mPa·s (*b*) and 37 mPa·s (*c*)

It is known from the Stokes equation that the particle sedimentation rate in a suspension is influenced by the particle size, density of the dispersed medium, as well as its density and viscosity. In this regard, in subsequent tests, in order to reduce the sedimentation rate of the suspension and the uniformity of its distribution in the volume, the viscosity of the dispersion medium was increased. In filtration experiments, this was done by adding water-soluble PAA to the suspension. As a result, solutions with viscosities of 15 and 37 mPa·s were obtained at various concentrations of PAA.

At the end of injection of a suspension with a dispersion medium with a viscosity of  $\mu = 15$  mPa·s, a dependence close in dynamics to the previous test was obtained (Fig.4, *b*). The pressure did not exceed 1 atm with a suspension flow rate up to 90 cm<sup>3</sup> (75 % of the suspension volume). A sharp jump to 7.8 atm occurred only at a flow rate of 100 cm<sup>3</sup>, which cannot be considered a satisfactory result.

In the third test (Fig.4, *c*) with a dispersion medium viscosity of 37 mPa·s, the suspension was stabilized. The injection pressure reached 1 atm even when pumping 10 cm<sup>3</sup> of the suspension, The sporadic peaks in the graph indicate colmatation of the fracture with polymer particles. Further, the injection pressure reaches a level with a median of





2.5 atm with a maximum value of 4 atm. At the same time, the permeability of the fractured core model decreased several times from 2.01 to 0.120  $\mu\text{m}^2$ , which is comparable with the conductivity of pore channels with medium permeability.

In field conditions, the addition of PAA increasing the polymer viscosity can be effectively replaced by mechanical mixing of the suspension. This process is difficult to model in filtration tests, and it requires additional field experiments.

To assess the necessary technological characteristics of the polymer gel injection process, taking into account the scale effect, we compare the conditions of filtration tests with field conditions. Assuming that the BFZ length is 1 m and the injection pressure is 300 atm, the calculated pressure drop per 1 cm of the BFZ is 3 atm. The maximum polymer injection pressure  $P_{\text{max}}$  obtained in the experiment with  $\mu = 37$  mPa·s did not exceed 4 atm, which gives a pressure drop of 1 cm – 1.3 atm with a core length of 3 cm. Accordingly, filtration experiments allow us to expect that the strength characteristics of polymer particles allow the developed polymer to overcome the BFZ.

**Conclusion.** Based on the filtration tests of the developed polymer gel, the following conclusions were made:

1. Swollen particles of the considered polymer gel are able to pass into fractures with a diameter less than their own size at least 20 times. With their sizes in the dry state of 250-500  $\mu\text{m}$  and swollen – about 1700  $\mu\text{m}$ , they successfully enter the fracture with an openness of about 60-70  $\mu\text{m}$ .
2. The polymer suspension being in a static state is able to sediment. During the tests, it was possible to reduce the sedimentation rate of the particles of the preformed polymer by increasing the viscosity of the dispersion medium. Thus, the stability of the suspension increases with a significant increase in the viscosity of the dispersion medium.
3. Particles of polymer gel have the necessary strength for injection in the field.
4. It was found that fracture permeability during polymer injection decreased by 17 times and became comparable with the conductivity of pore-type layers.
5. Taking into account the carried out filtration experiments, the polymer composition is recommended for further experimental and industrial tests on the oil field.

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