# STUDY OF POSSIBLE USING THE POLYMER SOLUTIONS AS AGENTS OF OIL DISPLACEMENT IN THE FIELDS WITH ABNORMALLY LOW RESERVOIR TEMPERATURES

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*Rheological, structural and oil displacing properties of the solutions of polyacrylamide (PAA) and carboxymethylcellulose (CMC) are fully investigated in the conditions of abnormally low reservoir temperatures. Physico-chemical processes occurring at a contact of highly mineralized formation water with the polymer solutions of PAA and CMC, which are different in composition, in the pore space of the reservoir are studied. The possibility of increasing the efficiency of hydrodynamic influence on the reservoir in the conditions of the fields of the southwest Yakutia due to the use of displacing compounds on the water-soluble polymer base is established experimentally.*

At present more then 60 % of the recoverable oil reserves belong to the category of reserves, which are difficult for extraction. Oil reserves in such fields, with the acceptable technical and economic factors, can be developed only under the condition of using the physico-chemical methods of the influence on the oil reservoir [1]. Thereupon, the choice of the most efficient technological scheme of such influence, directed at the maximum reduction of the residual oil reserves, is of a particular urgency. In the world and domestic practice the pumping of margins of different chemicals including compositions on the water-soluble polymer base is widely used as the agents for reservoir pressure maintenance (RPM) and for the increase in the oil recovery ratio (ORR) [2, 3, 4, 5]. The use of water-soluble polymers allows to reduce substantially the conductance of filtration tracks for oil and water, to align the front of oil displacing with water and to extend the water-free period of well operation, which promotes the increase in oil recovery.

The wide application of polymer flooding is explained by its certain advantages. The method is good for recovering the oil with high viscosity in the conditions of different stages of the development of fields with the nonuniform permeability, different in properties and reservoir structure. Moreover, the above procedure can be performed at low expenses of reagents and do not require expensive and complex equipment. Shortcomings of the method, such as lowering of the stability of polymer solutions at high temperatures (thermal destruction) and mineralization of bed fluids, can be eliminated by a thorough choice of a polymer composition and its modification.

At present the wide commercial application of the above method of polymer flooding during oil production is based on the data of numerous research works. Yet one should note that in the world practice water-soluble polymers for RPM and for increasing the oil recovery ratio were not used and peculiarities of their behavior in a reservoir were not investigated.

Oil reservoirs in the southwest Yakutia (Irelyakhsky, Talakansky and Sredne-Botuobinsky fields) are characterized by very specific thermobaric parameters: abnormally low formation temperatures and pressures. Thus, formation temperatures of the above fields at a depth of 1100 to 2000 m are 12-16 ºC, which is 40-50 ºC lower than the world average temperatures (at the geothermal gradient being 3 ºC/100 m). Now in all the projects of the experimental-industrial exploitation the method of hydrodynamic influence (flooding) with the use of highly mineralized salt solutions is planned or is already applied. As is well known, during flooding the oil recovery ratio in the best conditions makes not more than 55-65 %, and a considerable portion of oil (to 70 % of the residual reserves), due to macroheterogeneity and high water mobility relative to oil, remains in the reservoir regions not covered with flooding.

Thorough investigation of the problem of compatibility of formations waters with the injected highly mineralized solutions, allowing for the individual chemical composition, ionic force of miscible solutions, possibility of competing reactions and low temperatures, allows to establish that at combining these solutions a considerable drop in the reservoir filtration characteristics occurs due to their intensive sulphatization and calcination [6]. To exclude the undesirable crystal formation and deterioration of oil phase permeability and to increase the efficiency of the hydrodynamic influence it was suggested to use polymer solutions as oil displacing agents.

The wide application of polymers for improving the flooding procedure is based on the ability of their water solutions, even at a low polymer concentration, to decrease considerably the relation of oil and water viscosities, anisotropy of the formation itself and to change rheological properties and structure of filtration flows of formation fluids [7]. For the accurate prediction of using any method of the increase in oil recovery one should thoroughly investigate the chosen oil displacing procedure in the laboratory conditions.

As in practice usually the polymer solutions with concentrations from 0,4 to 10 g/l are used, to study the rheological properties of PAA and CMC solutions in different conditions we use the solutions with concentrations of 0,5; 1; 2; 3; 4 and 5 g/l.

One of the important parameters of hydrodynamic influence is the correlation between viscosities of oil and RPM agent. The less this correlation, the more efficient is oil displacement in the reservoir. Table 1 presents the data on the correlation between viscosities of oil of the Irelyakh field (Yakutia) and polymer solutions under study and highly mineralized RPM solution being used at present.

Table 1

Correlation between the dynamic viscosity
of the Irelyakh field oil and RPM solutions

| № | Solution, concentration | $\eta=\eta_н/\eta_в$ | |
|---|---|---|---|
| | | 10 °C | 20 °C |
| 1 | Highly mineralized RPM solution (284,92 g/l) | 10,58 | 9,02 |
| 2 | PAA solution, 0,5 g/l | 15,38 | 12,44 |
| 3 | PAA solution, 1,0 g/l | 3,43 | 7,03 |
| 4 | PAA solution, 2,0 g/l | 0,37 | 0,43 |
| 5 | CMC solution, 0,5 g/l | 31,79 | 27,20 |
| 6 | CMC solution, 1,0 g/l | 30,23 | 23,78 |
| 7 | CMC solution, 2,0 g/l | 21,29 | 18,41 |
| 8 | CMC solution, 3,0 g/l | 15,62 | 15,85 |
| 9 | CMC solution, 4,0 g/l | 11,17 | 12,39 |
| 10 | CMC solution, 5,0 g/l | 6,90 | 5,910 |

One can see that PAA solutions with the concentration of 1,0 and 2,0 g/l and CMC solution with the concentration of 5,0 g/l are the most efficient for using as agents of oil displacing with relation to the discussed parameter.

It is established that temperature has a substantial effect on the parameter considered. Thus, for PAA solutions with the established efficient concentrations the correlation between viscosities of oil and displacing solution decreases with temperature drop and at the solution concentration of 1 g/l it reduces by half (Table 1). In comparison with the highly mineralized RPM solution, correlations between the viscosities of oil and RPM agent for PAA and CMC solutions at formation temperatures are lower by 3 and 1,5 times, respectively (Table 1).

To exclude the possibility of lowering of the reservoir capacity properties during the flooding procedure one should study peculiarities of the interaction between polymer solutions and formation water, i.e. their compatibility.

To determine the degree of polymer solutions' and formation water compatibility in a free volume the mixtures of formation water with PAA (1,0 g/l) and CMC (5,0 g/l) solutions have been prepared in the following proportions: 1:9, 2:8, 3:7, 4:6, 5:5, 6:4, 7:3, 8:2, 9:1 and their rheological characteristics have been studied at the temperature of 10 and 20 ºC (Fig. 1, 2).

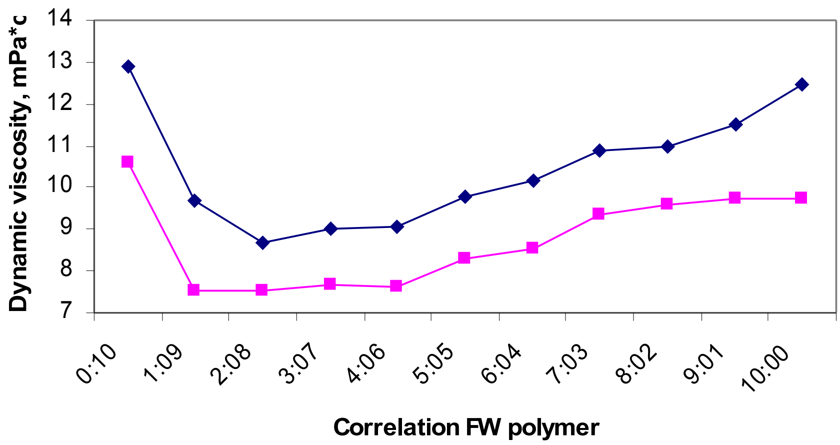



Figure 1. Dependence of the CMC solution dynamic viscosity (5 g/l) on the amount of the added formation water: 1 – at 10 ºC, 2 – at 20 ºC

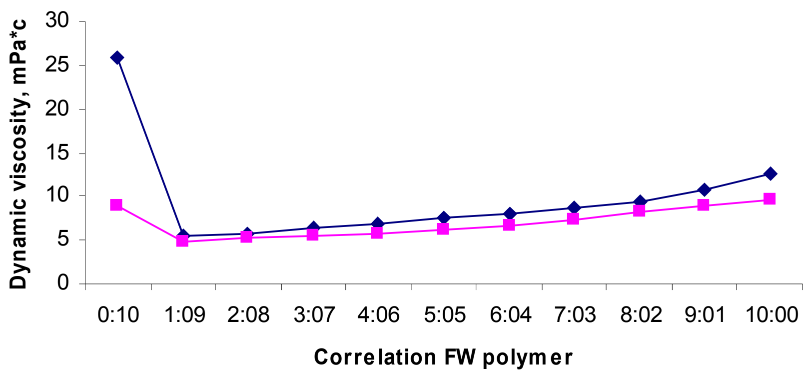



Figure 2. Dependence of the PAA solution dynamic viscosity (5 g/l) on the amount of the added formation water: 1 – at 10 ºC, 2 – at 20 ºC

Fig. 1, 2 shows that the character of the change in the polymer solutions' dynamic viscosity with concentration does not depend on temperature. Decrease in the viscosity of the polymer solutions under study at adding the formation water is explained mainly by its high mineralization (more than 200 g/l). It is known [8] that lowering of the polymer solutions' viscosity observed in the presence of some electrolytes is caused by their sorption on the active polar groups of a polymer, which prevents formation of cross-links influencing the solution viscosity.

To explain the chemical nature of the so-called salting-out effect the authors have performed the chemical analysis of the obtained mixtures of polymer solutions with formation water. A considerable decrease in the concentration of anions is established (content of chloride and hydrocarbonate anions decreases by 75 % and 94 % for PAA and by 77 % and 89 % for CMC, respectively), which is caused by the electrostatic adsorption of anions on the positive groups of macromolecules of polymers (Table 2).

Thus, on the basis of data obtained during studies on viscosity dependence on temperature and mechanism of interaction between polymers and formation water in a free volume one can choose reasonable polymer concentrations in solutions for using them as RPM agents: for PAA solution – 1,0 and 2,0 g/l, for CMC solution – 5,0 g/l.

Studies on oil displacing properties of the PAA and CMC solutions in the conditions close to the formation ones allow to obtain the permeability coefficient dependence on the volume of the polymer solution passing through a core sample.

It is established that in the case of the CMC solution (Fig. 3) the permeability coefficient decreases with the increase in the polymer concentration, which possibly is caused by the increase in shear stresses of the polymer at its filtration. Thus, at pumping the CMC solutions with different concentration through a sample in the amount corresponding to 4 volumes of its pore space the permeability coefficient at using the solution with 3 g/l concentration decreases by 5 times, with the concentration of 5 g/l – by 5,5 times, 7 g/l – by 4,4 times. Lowering of filtration characteristics of core samples occurs due to a partial adsorption and mechanical entrapping of a polymer by the porous medium.

Table 2

Chemical composition of mixtures
of PAA and CMC solutions with formation water

| Ratio FW:polymer | pH | $Ca^{2+}$, mol/l | Total hardness, mol/l | $HCO_3^-$, mol/l | $Cl^-$, mol/l |
|---|---|---|---|---|---|
| Formation water | | | | | |
| - | 5 | 4,99 | 5,93 | 0,00732 | 6,89 |
| PAA, 1 g/l (pH=7) | | | | | |
| 1:9 | 5 | 0,37 | 0,55 | 0,00122 | 0,238 |
| 3:7 | 4,5 | 0,344 | 3,57 | 0,00073 | 0,405 |
| 5:5 | 4 | 0,341 | 2,71 | 0,00146 | 0,928 |
| 7:3 | 4 | 3,588 | 3,44 | 0,00098 | 1,357 |
| 9:1 | 4 | 4,644 | 4,39 | 0,00049 | 1,738 |
| CMC, 5 g/l (pH=7) | | | | | |
| 1:9 | 5 | 0,302 | 0,437 | 0,00083 | 0,19 |
| 3:7 | 4,5 | 1,372 | 1,376 | 0,00098 | 0,555 |
| 5:5 | 4 | 2,452 | 2,222 | 0,00065 | 0,904 |
| 7:3 | 4 | 3,424 | 3,303 | 0,00049 | 1,301 |
| 9:1 | 4 | 4,055 | 4,043 | 0,00083 | 1,539 |

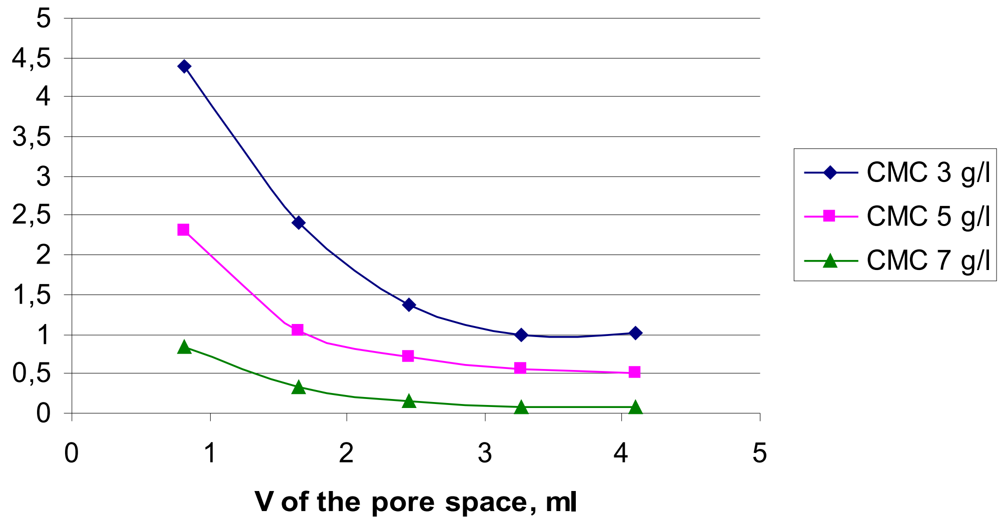



Figure 3. Dependence of the permeability coefficient on pore space
of the core sample from the Irelyakh GOF at pumping the CMC solution

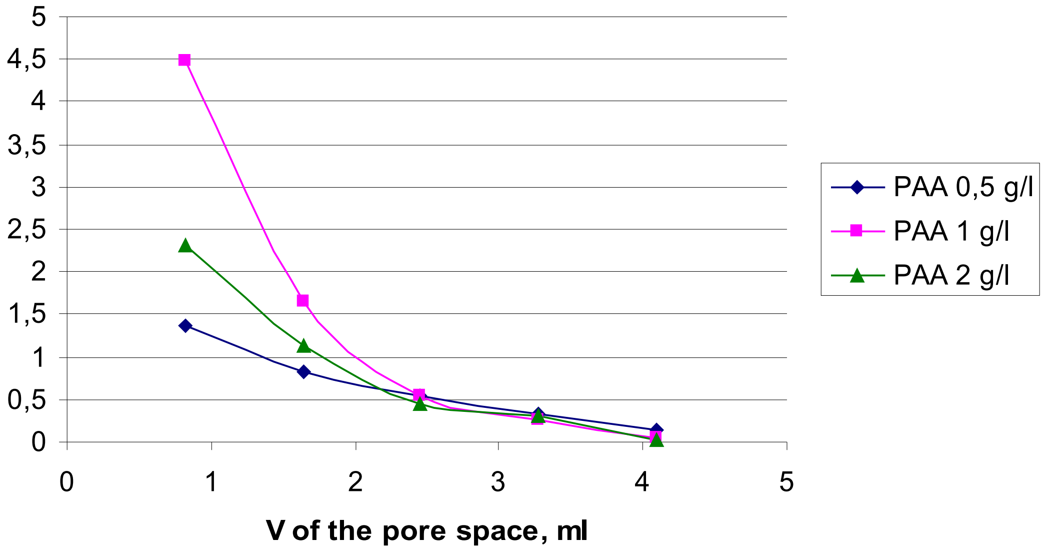
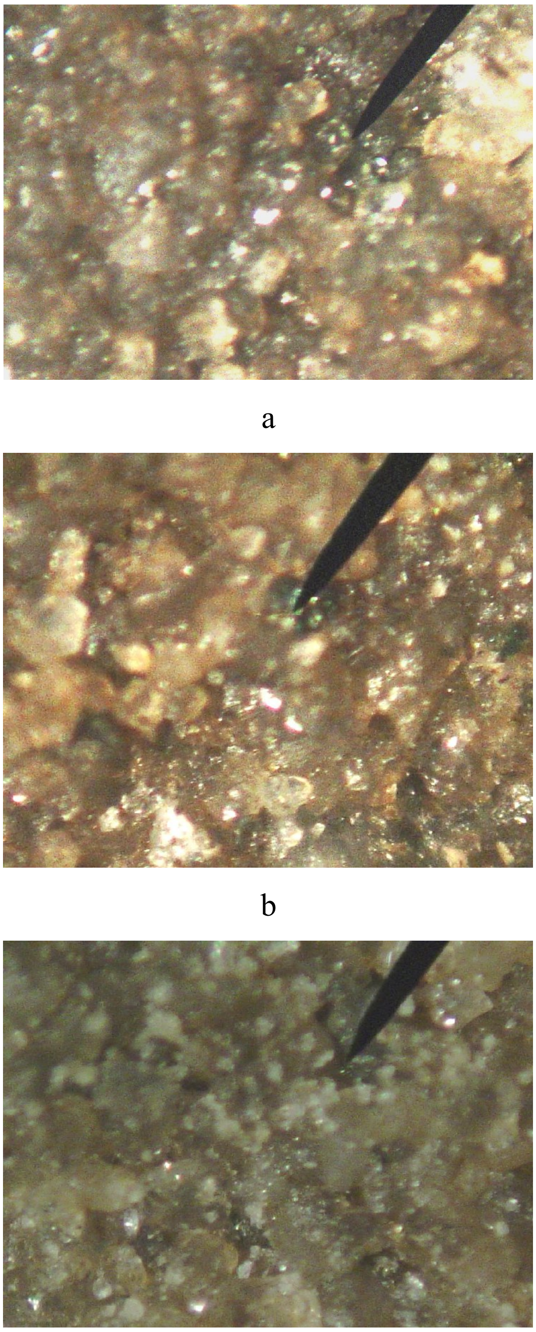



Figure 4. Dependence of the permeability coefficient on the pore space of the core sample from the Irelyakh GOF at pumping the PAA solution

The use of the polyacrylamide solution as the oil-displacing agent causes a sharper drop in the filtration characteristics of a core sample as compared with the carboxymethylcellulose solution. Thus, at passing of PAA solutions in the amount of 4 volumes of the sample pore space through a core sample one can observe the decrease in the permeability coefficient to 0; moreover, the above decrease is observed for all studied concentrations of the polymer (Fig. 4).

Fig. 5 presents microphotographs of the chips of core samples before and after polymer filtration through them. One can see a clear change in the “living section” of the sample surface during applying the displacing solution on the PAA base. The fig. 5 shows that a part of sample pores has been subjected to physically irreversible plugging and blocking by polymer particles. This phenomenon is caused by the so-called “resistance factor” and is dictated by non-Newtonian character of PAA solutions’ flow, as well as by polymer adsorption on the porous medium surface, which brings about a decrease in a size of filtration channels and changes their form.



a

b

c

Figure 5. Microphotographs (1x45) of the core sample
after polymer solution filtration:

a – the initial core sample;
b – after filtration by the CMC solution (5 g/l);
c – after the PAA solution filtration (1 g/l)

Also it must be noted that formation water of the Irelyakh field is characterized by high mineralization (396 g/l); calcium and magnesium ions' content makes 100,2 and 22,7 g/l, respectively; a decrease in the permeability coefficient is caused by the active process of salting-out of PAA macromolecules and the formation of the second phase (phenomenon of coacervation), which represents a more concentrated polymer solution.

Determination of the oil recovery ratio (ORR) depending on a type of a polymer and its concentration in the solution (Fig. 6) shows that solutions on the PAA base and the highly mineralized salt solution for RPM used at the Irelyakh field (Yakutia) are characterized practically by similar values of ORR (PAA solutions – from 37 to 40 %, RPM solution – 40 %). Low oil displacing properties of the above solutions are caused by chemical incompatibility of oil displacing agents with formation fluids in the existing thermobaric conditions. As a result, one can observe sedimentation of the solid calcium sulfate in the case of the RPM solution and sedimentation of polymer particles on the porous medium surface in the case of the PAA solution. The above phenomena bring about a substantial decrease in ORR and filtration characteristics of the reservoir.

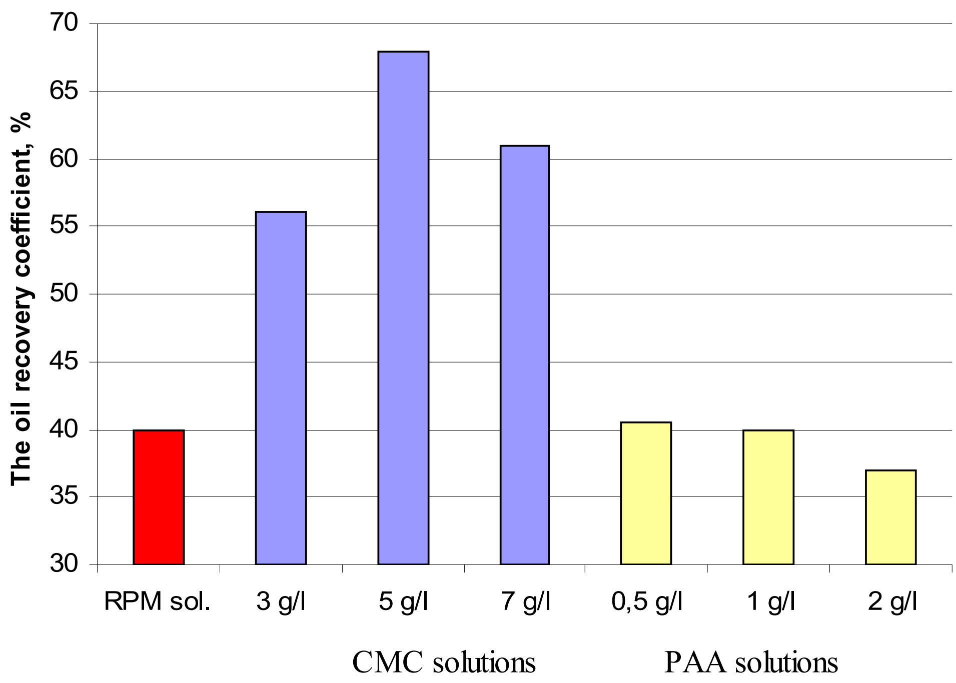



Figure 6. Dependence of the oil recovery ratio on CMC solution concentration at 10 ºC

Yet Fig. 6 shows that for the displacing solutions on the CMC base the oil recovery coefficient is by 1,4–1,7 times larger than that for the RPM salt solution. The CMC solution with polymer concentration of 5 g/l has the highest ORR (68 %) and its index of correlation between viscosities of polymer solutions and oil is 1,5 times larger that that of the RPM solution. Experimental studies show that the displacing solutions on the CMC base are characterized by a larger stability of properties during oil displacing as compared with the solutions on the PAA base. Therefore, the application of the carboxymethylcellulose solution with the concentration of 5 g/l as a basic oil-displacing agent can be more advisable for increasing the technical and economic indices of the fields characterized by high mineralization of formation fluids and low reservoir temperatures.

Therefore while studying the possibility of applying the polymer solutions as oil displacing agents in the fields with abnormally low reservoir temperatures one should investigate their rheological characteristics, oil-displacing ability with reference to a particular field and with an allowance for real reservoir temperatures, chemical compatibility of an oil-displacing agent with formation fluids and reservoir properties.

## REFERENCES

1. Khalimov E.M. Geological technology of prospecting and development of oil fields // Selected Proceedings (1958-2000). M.: IGiRGI. 2001. p. 103-108, 389-410.

2. Milovidov K.N., Kolchanova T.I. World practice of applying the methods of oil recovery increase// STJ "Petroleum and Gas Engineering". – 2002. –No.8. –p 46-48.

3. Yagafarov A.K., Kuznetzov N.P., Kudryavtzev I.A., et al. On the problem of the use of nonionic surface-active substances of low concentrations in the petroleum engineering // STJ "Petroleum and Gas Engineering" – 2004. – No. 11. -p. 16-18.

4. Sudobin N.G., Balakin V.V., Polischuk A.M., et al. Compositions for increasing the oil recovery on the biopolymer and carboxymethylcellulose base. Proceedings of the 5th Int. Conf. Chemistry of oil and gas. Tomsk. 2003. – p. 240-242.

5. Shveikina Yu.E., Shvetzov O.K., et al. New universal acrylic reagents for oil production // Proceedings of the 4th Int. Conf. Chemistry of oil and gas. –V.2. –p. 82-86.

6. Fyodorova A.F., Shitz E.Yu., Portnyagin A.S. Study of the processes occurring at interaction between the Irelyakh field formation water and a highly mineralized agent for reservoir pressure maintenance // Electronic scientific journal "Oil and Gas Business", 2007. http://www.ogbus.ru/authors/Fyodorova/Fyodorova_1.pdf .

7. Ermilov O.E., Remizov V.V., Shirkovsky A.I., Chugunov L.S. Reservoir physics, gas production and underground storage. – M.: Nauka. – 1996. – 541 p.

8. Tager A.A. Physico-chemistry of polymers. –M.: Goskhimizdat. –1963. – 528 p.