INVESTIGATION OF SELECTIVE PROPERTIES OF THE GEL-FORMING COMPOSITION FOR THE LIMITATION OF WATER INFLOW TO CARBONATE RESERVOIRS CONDITIONS

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ABSTRACT

The article is devoted to the problem of limiting water inflow in a production well. The authors consider the main features of the reservoir, which contribute to premature flooding. This paper presents the basic classification of plugging selective compositions, outlines the advantages and disadvantages of each type. Gel composed of carboxymethylcellulose, chromium acetate and copper sulfate was developed for water production restriction. An alternative way was offered to determine the optimal concentrations of plugging compositions on the change of the total porosity and x-ray density measured in the x-ray tomograph. Dynamics of the effective viscosity on the magnitude of the gap, simulating the fracture was obtained – the viscosity decreases logarithmically. Filtration experiments confirmed the selective properties of the gel-forming composition

Keywords: work over, gel-forming composition, rheological properties, selectivity, carboxymethyl cellulose, water production restriction, x-ray density, carbonate reservoir.


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1. INTRODUCTION

The modern period of oil production is characterized by the rapid transition of the key oil and gas fields to the final stage of development, which differs from previous stages by reducing the rate of extraction, low production rates and high water cut. According to this fact, in the last decade, oil and gas fields with inhomogeneous reservoirs, high-viscosity and high-sulfur
oil have been increasingly developed (Gavrilov and Grunis, 2012; Korobov and Podoprigora, 2018). The development of hard-recover oil and gas fields is difficult both technically and often is economically unprofitable. In some cases, it is advisable to eliminate the problems arising the development of «old» reservoirs. Premature water breakthrough and, in connection with this, high water cut is one such problem. The solution of this complication is an urgent challenge for oil production.

This problem is especially relevant for heterogeneous fractured-porous reservoirs, that are often represented by carbonate rocks. In such oil and gas reservoirs, because of high conductivity, fractures tend to be the key filtration pathways of formation fluids, while most of the hydrocarbon reserves can be concentrated in the matrix with a relatively low permeability (Blazhevich et al., 1981; Basargin et al., 2000; Basargin et al., 2002).

To reduce the increased water cut in well production, repair-insulation work is often performed. Basically, in the justification of the technology of work over lies the choice of plugging materials. Recently, when water flow is restricted, methods based on selective isolation of water saturated intervals are often used. This method consists in a selective modification of the phase permeability (hydrophobization) of the reservoirs, due to which the phase permeability through water channels is significantly reduced while maintaining the phase permeability for oil or gas. There are several classifications of reagents with a selective method of limiting the inflow of water. According to this classification, the compositions are divided into hardening, precipitating and gel forming. The disadvantages of the first two types are high cost, short supply, small mixing zone and poor stability in fractures. To limit the inflow of water in heterogeneous and fractured-porous reservoirs, the injection of gel-forming compounds is most often used (Korobov and Raupov, 2017; Tananykhin and Saychenko, 2017).

Gel-forming composition is based on the combined action of two or more reagents performing a different function (crosslinker, catalyst, destructor). Gels based on organic reagents (polyacrylamide, carboxymethylcellulose and "Hypan") allow the creation of large waterproofing screens, allowing the isolation of fractured layers (McLeod and Coulter, 1966; Nikitin, 2012; Altunina et al., 2014).

The object for the study is the Tourney-Famen complex of the Menzelinsky oil field. This object is composed of carbonate reservoirs characterized by high stratification factor, high heterogeneity and fracturing. A distinctive feature of this reservoir is the high mineralization of the reservoir water ((Mendonça & Andrade, 2018); Jaramillo, 2018).

2. METHODOLOGY
As a solution to the problem of high water cut, a gel-forming composition consisting of carboxymethylcellulose, an organic chromium (III) salt and an aqueous solution of copper sulfate was developed at the Saint Petersburg Mining University. These reagents are nontoxic, generally available and have a low cost.

Experimental studies of determining the optimum concentrations of reagents, as well as the rheological, selective and filtration properties of the gel-forming composition were carried out on the modern and unique equipment of the oil recovery enhancement laboratory at the Mining University. In this paper, the following parameters were determined: X-ray density, overall porosity of the gel-formed composition, the dynamics of the effective viscosity, the residual resistance factor, and selectivity (Podoprigora and Korobov, 2017; Raupov and Podoprigora, 2017; Raupov and Korobov, 2018).
To determine the optimum copper sulfate concentration in the composition, an experiment was carried out to determine the X-ray density and the overall porosity of the composition. The studies were carried out using a Skyscan 1174 X-ray scanner. The scanner has a closed metal-ceramic X-ray source with a long service life, a scintillation screen, a CCD camera, zoom lens, a manipulator for positioning and rotating an object with an electronic system for supplying an X-ray source and a camera and for controlling the manipulator. It is possible to investigate a three-dimensional model of the studied samples (core, gel, etc.) and to study the structural characteristics of gel-forming compositions on this tomograph (Roschin, 2014; Singh and Mahto, 2016).

As for the laboratory experiment, the solution was prepared and poured into a plastic vessel of 20 ml volume. Further, the composition was scanned, a three-dimensional model of the gel was created throughout the volume of the vessel. Then, based on the three-dimensional model, the program calculated the exponent of open porosity. Also, the program determined the upper and lower limits of light absorption and the number of Hounsfield was calculated as their difference. After cross-linking of the composition, the actions were repeated.

3. RESULTS
The Hounsfield number is used to quantify the X-ray density of substances. In the physical sense, the Hounsfield number indicates a weakening of the X-ray radiation with respect to distilled water. The results of the studies for determining the optimum copper sulfate concentration are presented in Figures 1, 2.

![Figure 1](http://www.iaeme.com/IJCIET/index.asp)  
**Figure 1** Dependence of the difference between the upper and lower limits of the Hounsfield numbers vs the concentration of copper sulfate

As can be seen from Figure 1, the largest change in the Housefield index between the prepared composition and the cross-linking is achieved at a copper sulfate concentration of 0.7% by weight. Therefore, it can be assumed that at a given concentration of copper sulfate, the composition will have the greatest plastic strength.
Figure 2 Dynamics of total porosity during gel crosslinking

The indication of the total porosity directly affects the density and strength of the gel - the lower the porosity, the higher the strength, since in the entire volume space of the gel there will be the least amount of air globules, thereby the gel will be more integral. As can be seen from Figure 2, with an increase in the concentration of copper sulfate, the porosity index decreases and reaches its lowest value at a concentration of 0.7% by weight. Further increase in porosity is due to the supersaturation of copper sulfate, which indicates the optimality of copper sulfate concentration equal to 0.7% by wt. for a composition with a carboxymethylcellulose content of 5.5%, chromium acetate 1.0-1.2%.

For the possibility of predicting rheological properties in real fractures and pores, an experiment was conducted to study the dynamics of the effective viscosity from the size of the gap to be set. The studies were carried out on Anton Paar's unique MCR 102 rheometer, which is highly accurate when studying the properties of various liquids. The device is described in detail in works (Strizhnev, 2010; Coil, 2015; Shagiakhmetov et al., 2018). With the help of this device, it is possible to change the gap in the "plate-plate" system to simulate the flow of liquid in a fracture with a gap clearance up to 1 mm. In our case, this possibility was used to study the behavior of the gel-forming composition in the fractures of the formation of various gap clearances.

The experiment was carried out as follows. A sample of the gel-forming composition was placed on the plate, a certain gap and a reservoir temperature of 25°C was set. Next, a shear rate of 5 s⁻¹, characterizing the velocity of movement in the formation, was set and the effective viscosity was measured. During the experiment, the following gaps were established: 0.2; 0.3; 0.5; 0.7; 1.0; 1.5 and 2.8 mm.

Figure 3 shows the dynamics of the effective viscosity from the size of the gap.
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Figure 3 Dynamics of the effective viscosity from the size of the gap clearance

The presented graph shows the logarithmic dependence of the effective viscosity on the gap size. The reliability of the approximation is more than 99%, which indicates a high probability of predicting parameters such as the induction period of gelling and the effective viscosity for real dimensions of the formation.

The proposed waterproofing composition consists mainly of water, hence the likelihood that the gel will penetrate into the highly permeable interlayers, creating an irresistible screen there, thereby involving a low-permeability part of the reservoir saturated with oil. To confirm this theory, a filtration experiment was performed to evaluate the selective properties of the composition. The studies were carried out on a bench consisting of two parallel-connected core holders and a filtration unit FDES-645 (Coretest System). In the core holders were placed two cores of the Tournai-Famenian reservoir of the Menzelinskoy oil field. One core was saturated with oil, the other - with formation water (Coil, 2015; Podoprigora, 2017).

The study was carried out in several stages: the determination of phase permeability for water and oil, the total injection of waterproofing composition in the amount of 5 pore volumes, holding the cores at rest for 24 hours, remeasuring the phase permeabilities for oil and water, injecting the destructor and final measurement of the oil permeability and water. At the end of the experiment, the following parameters were calculated: residual resistance factor, selectivity coefficient and permeability deterioration (Gaivoronsky et al., 2000; Podoprigora et al., 2016, Rogachev and Kondrashev, 2016)

The results of the filtration tests are presented in Figures 4, 5 and in Table 1.

Figure 4 Dependences of pressure gradients vs pore volumes when water injecting during an experiment to assess the selectivity
Figure 5 Dependence of pressure gradients vs pore volumes when oil injecting during an experiment to assess the selectivity.

For the oil-saturated core sample, the residual resistance factor after injection of the gel was 1.24 units, for a water-saturated core sample it was 19.83 units. Thus, the gelling composition greatly reduces the permeability of the water-saturated fractured core sample, which confirms its selectivity (Podoprigora et al., 2015; Tananykhin and Shagiakhmetov, 2016; Podoprigora and Raupov, 2018).

Table 1 Results of the filtration experiment for the assessment of the selective effect of waterproofing composition

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit of measurement</th>
<th>Before injection of the composition</th>
<th>After injection of the composition</th>
<th>After injection of destructor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gradient of oil injection pressure</td>
<td>MPa/m</td>
<td>76.82</td>
<td>95.59</td>
<td>81.7</td>
</tr>
<tr>
<td>Gradient of water injection pressure</td>
<td></td>
<td>4.10</td>
<td>81.25</td>
<td>54.47</td>
</tr>
<tr>
<td>Permeability for oil</td>
<td>×10⁻³ mkm²</td>
<td>0.16</td>
<td>0.12</td>
<td>0.15</td>
</tr>
<tr>
<td>Permeability for water</td>
<td></td>
<td>3.62</td>
<td>0.18</td>
<td>0.27</td>
</tr>
<tr>
<td>Residual resistance factor for oil-saturated core sample</td>
<td>units</td>
<td>-</td>
<td>1.24</td>
<td>1.04</td>
</tr>
<tr>
<td>Residual resistance factor for water-saturated core sample</td>
<td></td>
<td>-</td>
<td>19.83</td>
<td>13.30</td>
</tr>
<tr>
<td>Factor of selectivity</td>
<td></td>
<td>-</td>
<td>16.00</td>
<td>12.78</td>
</tr>
</tbody>
</table>

The factor of selectivity after injection of the composition is 16 units, after destruction of the gel – 12.78. This once again confirms the selective ability of the waterproofing composition.

4. CONCLUSION

As a result, it can be concluded that the proposed plugging composition significantly affects the watersaturated interlayers, reducing the phase permeability for water. Based on the studies performed, it is possible to draw the following conclusions:

1. An alternative method for determining the optimum concentrations of the reagents of the gelling agent is proposed, based on the dynamics of the total porosity and the X-
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ray density, depending on the ratio of the components concentrations of the composition.

2. The dependence of the rheological properties of the gel-forming compositions vs the size of the gap simulating the fracture is established. The dynamics of the change in the effective viscosity of the composition vs the size of the gap is logarithmic with a high confidence.

3. The selectivity of the waterproofing composition was confirmed. The gel reduces the phase permeability in the water-saturated interval of the reservoir to a greater extent than in the oil-saturated layer.

REFERENCES


