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Development of water-shutoff composition on the basis of carboxymethyl cellulose for fractured and fractured-porous oil and gas reservoirs

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Abstract. The article is devoted to solving one of the most important problem of the oil industry – the high level of water cut. Different kinds of water shutoff agents were studied in the work and its advantages and disadvantages were claimed. The authors proved an actuality of the water inflow limitation problem in fractured and fractured-porous reservoirs. The laboratory research has established the dependency of the gelling kinetic and strength characteristic of the shutoff composition on reagent concentration by which optimum reagent concentration can be prompt determined for specific geological conditions. In addition, the gelling induction period was measured at shear rate that modelled a movement of the composition in fractured-porous reservoir for different spacing gaps between two resistors plates of the Rheotest unit. The determination of residual resistance in the sample of the rock with an artificially created crack was carried out by the filtration experiment.

Key words.
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1. Introduction

Modern period of oil production is characterized by deterioration in structure of reserves of oil fields, involvement in the development of heterogeneous reservoirs and fast transfer of the main operational objects to a final stage of the development accompanied with the significant level of water cut and low rate of wells oil discharge [1]. Currently, an accent of oil and gas fields development is moving to fractured reservoirs, because of it contains approximately 60 % of world's hydrocar-

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bons reserves [2]. The prominent feature of fractured reservoirs is a vast influence of discrete systems on fluid flow in a formation, such as: cracks systems, system of open channels inside cracks systems and cavities [3]. Fractured reservoirs are, basically, represented by rock blocks which separated by cracks systems. Depending on filtration and capacitor properties of a matrix (skeleton) of a rock two main types of fractured reservoirs can be determined [4]:

1. Fractured without porosity. These reservoirs are compiled by impenetrable blocks which do not contain hydrocarbons inside. In these reservoirs oil locates in a system of associated cavity where the filtration happens. The volume of the cracks system usually varies from a few thousandths to one hundredth share of the volume of the rock (according to the data of complex rock samples field researches).

2. Fractures with porosity. Unlike previous one the major oil locates inside blocks of the porous environment where the cracks have a function of associated channels in which the filtration happens. The secondary porosity normally takes no more than 1 % of the whole rock volume.

In [5] stated that to restrain the too-fast rising of water cut in oil wells in Ordovician fracture-cavity carbonate reservoirs in Tahe Oilfield, two effective water shutoff agents (modified tannin gel water shutoff agent and flexible water shutoff agent) couls be used. The laboratory study of fracture-cavity carbonate cores plugged with the two agents shows that the increase of the agent injection leads to an increase of depth of plugging section and higher breakthrough pressure gradient in the initial stage; the accumulation of the shutoff agent makes the flow path narrower when a certain depth of plugging section is reached, raising the residual resistant factor. According to [6] the crosslinker/polymer ratio had more effects on the gelation time than did the polymer concentration and their interaction. A response surface method provides an optimum gel formulation. Core flooding experiments reveal that a significant permeability reduction on the sand pack cores can be achieved at reservoir conditions, when it is treated with an optimum gel formulation. Hence, this gel system may be suitable in the water shutoff job required for enhanced oil recovery from the oil fields.

The object of the study is oil-saturated layers with commercial oil content timed to Upper Devonian and relates to carbonate basins that contain about 95 % of the whole amount of oil reserves. Reservoir formations are formed by brown organogenic-detrital porous micro-cracked oil saturated limestones. These layers are described by a high stratification factor (>3). Reservoir water has a high mineralization (>100 g/l). Carboxylmethyl cellulose, organic salt of chromium (as a crosslinker) and aqueous solution of copper sulfate (as a catalyst) were used as a raw material for the gelling composition preparation. These reagents are non-toxic, widespread and cheap. Experimental of determination of physic-chemical, rheological and filtration properties of the gelling composition were carried out on a modern equipment in a laboratory of Production Stimulation Engineering in Saint-Petersburg Mining University. In the research the following parameters were determined: gelation time, plastic strength, induction period of gelation and residuary resistance coefficient. Researches of strength and gelation time dependence on carboxymethyl cellulose concentration, crosslinker and catalyst were held for determination of the optimum concentration of the developed water-shutoff composition. The gelation period was measured in according to following principle: the compound was transfused to a transparent glass right after the mixing and covered by a piece of foil. Then, the glass was being tilted to an angle of 450 every 15 minutes. The compound could be considered gelled in case of the angle of the meniscus remained unchanged. Gelling composition is acceptable for production in case gelation time is between 2 and 24 hours [6].

The plastic strength was measured on a cone-and-plate rheometer (Rebinder machine) as follows: the cone of the known weight was fallen into the gelling composition and kept on there for 15 minutes. In the result, cones penetration depth into the gel was measured and the endpoint of the plastic strength was calculated. The compound is acceptable in case of the plastic strength is 3000 Pa [3].

Figure 1 shows dependence graphs of the gelation time and plastic strength vs the concentration of copper sulfate.

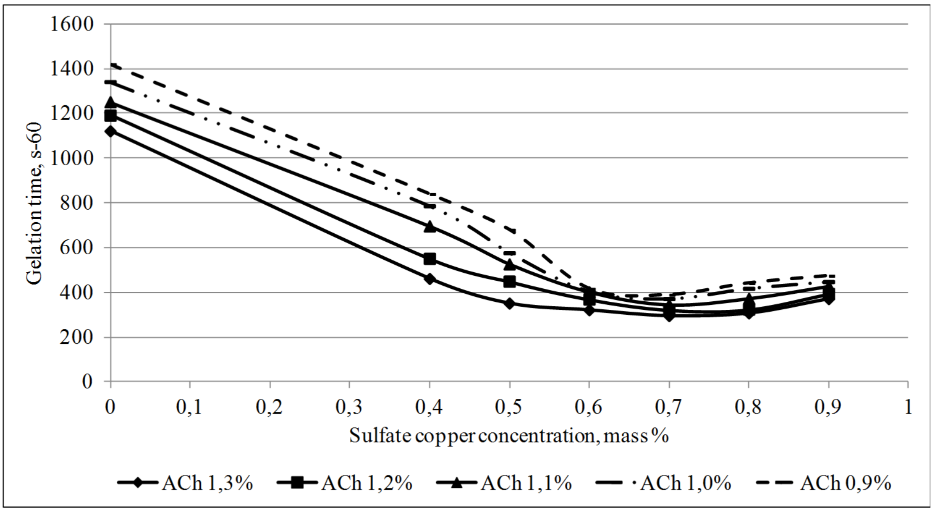

Fig. 1. The dependence of the gelation time vs the copper sulfate concentration

As can be seen from Fig. 1, all measured concentrations of copper sulfate and chrome acetate (III) are placed within the valid time of gelation. Furthermore, it should be taken into account, that the gelation time changes insignificantly when the concentration of the copper sulphate is higher than 0.6 %.

For induction period of gelation metering a rheometer Anton Paar MCR 102 which has a high measurement accuracy of different liquids was used. On the facility, the gap between the two plates can be changed in order to study the dependence of the induction gelation period vs the gap size. The method of the induction period determination is described further. The sample of the gelling compound is poured on the plate by a dosimeter; a certain gap, a temperature of 25 °C and a constant shearing rate of 5 s^{-1} are established [7]. The experiment used to be stopped with the growth of the effective viscosity. The induction period of gelation was defined as time at which the effective viscosity remained unchanged with respect to the initial one.

Figure 2 shows the dependence of the effective viscosity of the gelling compound vs the time and the gap width ($\gamma = 5c - 1$).

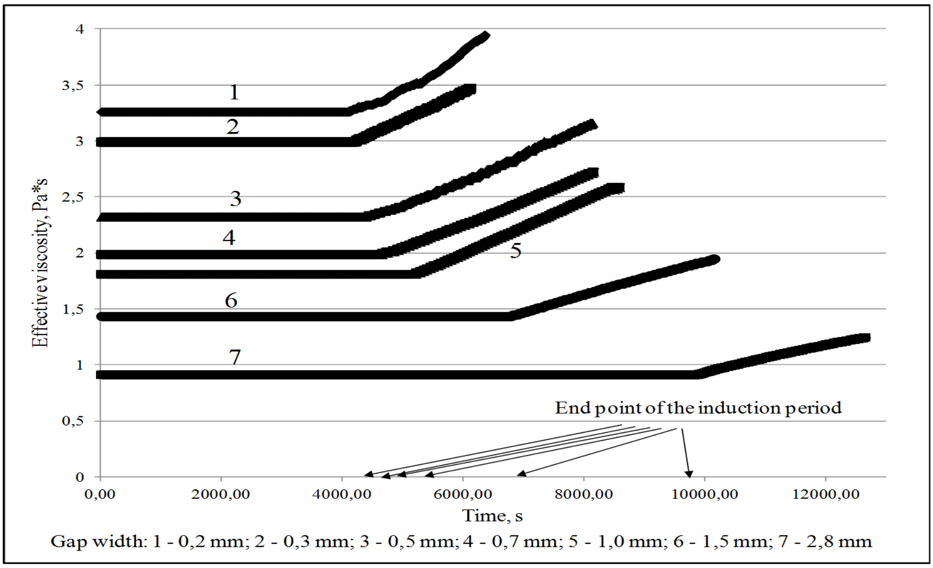

Fig. 2. Dependence of the effective viscosity of the gelling compound vs the time and the gap width ($\gamma = 5c - 1$)

The induction period of gelation is higher than 1 hour with different gaps. It is enough for pumping it into a fracture system.

To evaluate the effect of the gelling compound on the indicators of a fractured-porous reservoir development the filtration experiment of the residual resistance factor determination was conducted. The research was carried out on a filtration unit FDES-645 (Corotest Systems Corporation, USA). The rock sample from Mezelinskoe oil field with a pre-generated fracture was placed in a core holder [7]. The sample was saturated with a formation water with mineralization of 180 g/l in advance. At the first stage the formation water with a continuous flow of 0.5 ml/min was pumped up until pressure level-off. After that the gelling composition in a volume of the porous space was pumped. After the operations, the unit was stopped for 24 hours in order of the gelation. The operation of the water pumping was repeated then. Finally, the residuary resistance coefficient of the fractured rock sample which shows the permeability reduction of the sample after the treatment was calculated as

$$R_{>\mathrm{AB1}} = \frac{\operatorname{grad} P_2}{\operatorname{grad} P_1},$$

where $R_{>\mathrm{AB1}}$ is the residuary resistance coefficient after the treatment, $\operatorname{grad} P_1$ is the pressure gradient before the insulation process (Pa/m) and $\operatorname{grad} P_2$ is the pressure gradient after the insulation process (Pa/m).

Figure 3 and Table 1 represent the results of the filtration experiment.

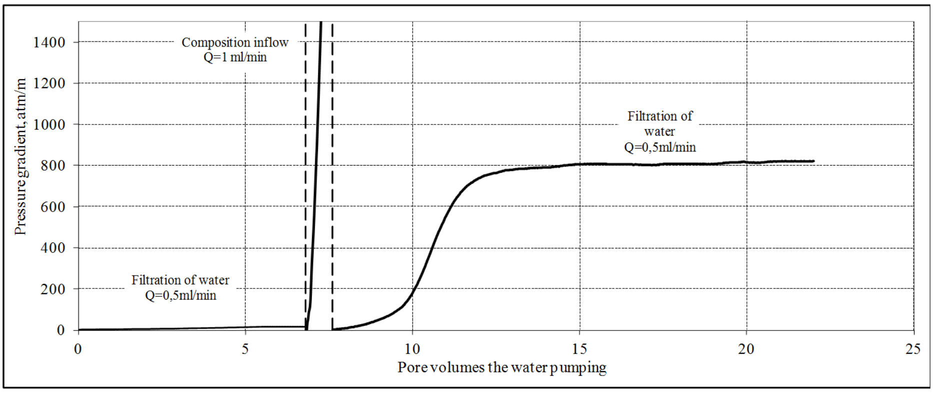

Fig. 3. Dependence of the pressure gradient on the pore volumes, the water being pumped on the saturated fractured-porous rock sample

Table 1. Experimental results

Parameter	Measure	Before the treatment	After the treatment
Pressure gradient for water	MPa/m	1.80	82.17
Core permeability	$\times 10^{-3}$ mkm^2	8.25	0.18
Permeability reduce factor	%	-	–97.8
Residuary resistance coefficient	u	-	45.7
Maximum pressure gradient for the composition	MPa/m	325.59	

As can be seen from Figure 3 and Table 1, the water permeability in the core sample with an artificially created fracture decreased 46 times. The maximum pressure gradient for the composition is 325.6 MPa/m. It can be concluded that proposed compound insulates cracks effectively thus allowing to displace an oil from low-permeability channels.

2. Conclusion

The gelling organic shutoff composition was developed for water inflow limitation in fractured-porous rocks. The main component of the compound is carboxymethyl cellulose (the mass fraction is 5.5 %), chrome acetate (III) (mass fraction is 1–1.1 %) used as a crosslinker, copper sulfate used for increase of the plastic strength of the composition is recommended as a densifier.

It is found that the ratio of the concentrations of chromium acetate and copper sulfate allows adjusting the gelling time and strength properties of the composition. The relationship between the induction period of gelation period at shear rate in fractured-porous reservoir and the gap width obeys an exponential function. Its value is sufficient to inject the composition to a depth necessary for stability of the gelling compound to water breakthrough and blocking the formation of the treated interval.

The filtration experiment proved that the proposed composition can effectively insulate the fractured reservoir intervals; water permeability is reduced 46 times after the injection of the compound.

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