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Studying Properties of Polymer Solutions and Efficiency of Crude Oil Displacement in Specific Conditions of Deposits in Southwestern Yakutia

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This paper studies features of rheological behavior and the level of oil displacement for solutions with various concentrations of carboxymethylcellulose (CMC) and polyethylene glycol (PEG) in the conditions of collectors with low reservoir temperatures and high mineralization of reservoir water. The purpose of this study is the searching for and adaptation of existing technological methods for displacement in conditions of oil extraction in deposits of the Republic of Sakha (Yakutia). Physico-chemical oil-displacing properties of CMC and PEG polymers were studied at the laboratory, which showed that tested displacement solutions based on Na-CMC 5.7 g/l of PEG and 30 g/l have high values of Oil Recovery Factor (ORF) and can be recommended for practical use. However, in order to substantiate the use of the polymer flooding method, the expected technological effect manifested in additional delivery of oil and increased ORF is not enough. Therefore, we calculated the cost-effectiveness on the basis of comparing incurred cost of the basic variant and development using water-soluble polymers. Calculations showed that the use of PEG would be unprofitable, since costs of the activity and crude oil production exceeds the revenue from selling the produced oil. Thus, in order to improve the flooding method in deposits of the southwestern Yakutia, it is recommended, according to comprehensive research, to use carboxymethylcellulose solution at a concentration of 5 g/l as the base displacing agent.

Key words: Carboxymethyl cellulose (CMC), Polyethylene glycol (PEG), Oil recovery, Specific layer conditions.

Efficiency of industrial oil recovery using well-known development methods in all oil-producing countries today is considered unsatisfactory, despite the fact that consumption of oil products in the world is growing every year. The average ultimate oil production in oil beds in different countries and regions ranges between 25 and 40 %[1].

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The Republic of Sakha (Yakutia) attracts investors due to its huge (1.5 -2 bln. tons) reserve of the "black gold"[2].Thus, by 2020, oil production in Yakutia will increase to 20 mln. tons per year[3]. At the moment, government's balance of revenues and expenditures in the republic includes 34 hydrocarbon deposits, including 15 oil deposits. The largest are Chayandinsk, Talakansk, Srednebotuobinsk and Taas-Yuryakhsk deposits, which are almost ready for commercial development; Talakansk, Irelyakh and Srednebotuobinsk deposits are in pilot operation. Nevertheless, for any deposit the methods of raw

material extraction, technology of oil production are relevant, whereof choice depends on the conditions in each particular collector[4]. The main feature of the oil deposits in the Southwest Yakutia is abnormally low reservoir temperature and pressure. Thus, the reservoir temperature of the deposits at the depth of 1100 to 2000 m are 12-16°C which is 40-50°C below the world average (with geothermal gradient of 3°C /100m). Besides, the specificity of these deposits is also significant (<300 g/l) mineralization of reservoir water. This means that in order to prevent any loss of well productivity due to deterioration of reservoir properties, studying characteristics of displacing agents and determination of compatibility of intrastratal fluids with fluids injected into the bed becomes relevant. Indeed, the research performed by the RAS Oil and Gas Institute showed on the example of Irelyakh deposit located near the south-western outskirts of Mirny that the use of highly mineralized displacing solutions is inefficient, since it leads to sulphatisation and calcination of collector rock, which leads to a considerable reduction of the production well yield[5].

Thus, our research and its results are aimed at finding and adapting existing technological methods of displacing in the conditions of oil extraction in the deposits of Sakha (Yakutia).

Since the method of polymer flooding has been successfully used to extract high viscosity oil[6], in the conditions of various stages of deposit development, and can be fully integrated into the general scheme of development at the majority of oil deposits in South-Western Yakutia, this study was aimed at experimental study of increasing oil production through the use displacing polymer compositions.

MATERIALS AND METHODS

Sodium carboxymethyl cellulose (Na-CMC) of Kamcell - O grade, TOR 2231- 002 - 50277563 - 00. The choice of displacement solution is determined by the following: aqueous solutions of Na-CMC and polymer flooding method have been widely and successfully used and are used now to improve efficiency of oil displacement at deposits with various petrophysical and geological characteristics, including abroad, in the United States, China, and so on[7,8]; Na-CMC is a modified natural polymer, and, if compared to other synthetic analogues, such as polyacrylamide (PAA), is less scarce and less expensive, which is economically important[9].

Polyethylene glycol (PEG-1500, PEG-6000). Structural formula has the following form: $HO\text{-}CH_2\text{-}(CH_2\text{-}O\text{-}CH_2\text{-})n\text{-}CH_2\text{-}OH$, where n = 1500 or 6000. The choice of polymer as a base for the displacement solution is determined by the fact that polyethylene glycol is an agent that increases efficiency of secondary oil recovery, which is also widely used in the world for oil production.

Calcium chloride ($CaCl_2$), of Labtech grade, TOR 6-09-5077-83. The use of this salt is stipulated by the fact that the chemical composition of the reservoir water in the Ulahansk and Butuobinskhorizons of the Irelyakh gas and oil deposit, according to the classification of groundwater in terms of mineralization, belongs to high salinity mineral waters (160 g/l and more)[10] of the calcium chloride type.

Oil from the Irelyakh Gas-and-Oil deposit. Oil from the Irelyakh Gas-and-Oil deposit belongs to light sweet oils with sulfur content of 0.45%, average density of 853 kg/m^3 and viscosity of 17-21 mPa.s [11]. Viscosity of prepared PEG solutions, Na-CMC at 10°C and 20°C was determined according to GOST 33-82 [12]. Density of aqueous solutions with various polymers concentrations was determined at 10°C and 20°C according to GOST 3900-85.

Oil-displacing properties of polymer solutions were determined using Core Permeability Measurement Unit UIPK - 02M that is a part of AKM research complex in accordance with GOST 26450.2-85 at 10°C. Reservoir rock at the Irelyakh Gas-and-Oil deposit in Sakha (Yakutia) is mainly composed of sandstones with prevailing voids homogeneity. Average porosity is 9.47%, average permeability for gas is 0.23 μm^2. In determining the filtration characteristics, artificial model of porous medium, pressed sandstone was used. In order to determine the oil-displacing capacity of solutions on the basis of water soluble polymer and highly mineralized displacement solution, core samples were saturated with degassed oil from the Irelyakh Gas-and-Oil deposit.

RESULTS

It is the first time that comprehensive study has been made of rheological and oil-displacing properties of solutions based on ionic and nonionic polymers in simulated conditions of deposits characterized by low reservoir temperatures and burdened by high salinity of reservoir water.

As a result of studying physical and chemical properties of polymer solutions (Table 1) water-polymer solutions with best technological propertieswere found, i.e. with the maximum viscosity at 10°C and the minimum viscosity at 20°C: - CMC 3, 5 and 7 g/l; PEG 20, 30 and 50 g/l. It has been established that the density of the solutions based on CMC and PEG remains virtually the same. Thus, in planning enhanced oil recovery methods based on injection of water-polymer solutions based on CMC and PEG in the conditions stated, one can confine himself to determining their viscosity at operating temperatures.

Efficiency of polymer influence largely depends on composition and quantity of salts in the reservoir waters and solutions that are used as the oil displacement agent[13].

Reduction in oil-displacing capability of polymeric solutions is determined by the fact that during preparation and contact between process fluids and reservoir water, molecular degradation occurs, chemicals are absorbed, precipitates are formed, and initial structures are inversed[14].

Table 1. Physical and chemical properties of polymer solutions

	CMC, 3 g/l	CMC, 5 g/l	CMC, 7 g/l	PEG, 20 g/l	PEG, 30 g/l	PEG, 50 g/l
Density at 10°C, g/cm³	0.997	0.994	0.996	0.997	0.998	1.006
Density at 20°C, g/cm³	0.998	1.006	1.010	0.995	1.002	1.006
Dynamic viscosity at 10°C, mPa.s	1.94	1.67	2.0	1.52	2.12	2.69
Dynamic viscosity at 20°C, mPa.s	1.30	1.39	1.67	1.22	1.58	2.01
Oil viscosity to polymer solution ratio at 10°C	5.7	5.3	4.1	5.8	4.1	3.3
Change of polymer solution viscosity after coupling with reservoir water (salinity 200 g/l), %	8.7	9.6	18.4	3.4	4.6	9.9
Change of polymer solution viscosity after coupling with reservoir water (salinity 300 g/l), %	9.8	11.0	20.5	2.0	2.2	10.8
Change of polymer solution viscosity after coupling with reservoir water (salinity 400 g/l), %	11.6	12.2	23.9	2.6	3.4	14.0
Oil recovery factor	56	68	61	31	61	33

Table 2. Comparison of cost-effectiveness in case of using various displacement agents (on the example of the Irelyakh Gas-and-Oil deposit)

Displacement Agent	Amount of oil produced, thousand tons	ORF, %	Costs of production 1 ton of oil, thousand rubles	MET, mln. rubles	Profit, mln. rubles	Economic effectiveness
HMS	61.0	40	2.5	265.8	252.7	-
PEG(20 g/l)	47.3	31	4.99	206.1	78.2	70 % less
PEG(30 g/l)	93.0	61	4.69	405.2	209.0	17 % less
PEG(50 g/l)	50.3	33	8.35	219.2	-85.9	Recovery is unprofitable
CMC(3 g/l)	85.4	56	2.7	371.5	336.8	33% more
CMC(5 g/l)	103.7	68	2.52	451.8	400.5	58% more
CMC(7 g/l)	93	61	2.94	405.2	344.0	36% more

It has been established that displacement solutions based on CMC and PEG are chemically compatible with highly mineralized reservoir water of calcium chloride type (salinity 200, 300, 400g/l), since in their interaction, the maximum change in viscosity is not more than 24 %. Thus, the thickening ability of PEG and CMC in contact with highly mineralized reservoir water is not reduced, and no polymer degradation is observed.

Amount of recovered oil characterizes displacing ability of the displacement agent[15]. As a result of studying oil-displacing properties of polymer solutions in a wide range of concentrations in simulated conditions of low reservoir temperatures, it was found that their effectiveness is also determined by rheological properties of the solutions (Figure 1). Thus, solutions of PEG (30 g/l) and CMC (7 g/l) correspond to equal values of both ORF (61%) and dynamic viscosity (2.1 mPas). It has been shown that there exists an optimum of rheological characteristics that corresponds to the maximum level of ORF; the maximum displacement effect is observed when the value of oil viscosity to the polymer agent ratio is between 4.1 and 5.7. It should be noted that ORF of the polymer solutions specified is 21 to 28% higher than the oil displacement agent currently used at the Irelyakh Gas-and-Oil deposit.

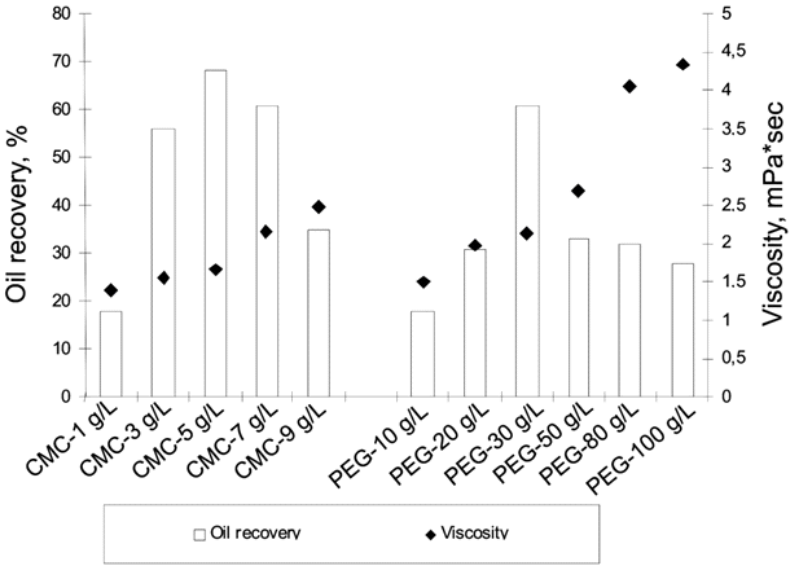

Fig.1. Dependence of dynamic viscosity and oil recovery ratio on the concentration of polymer in displacement composition

DISCUSSION

For most deposits in the Republic of Sakha (Yakutia) typical oil extraction method is seasonal flooding with overcompensation of oil extraction by injecting highly mineralized displacement solution. Thus, the undisputed and economical advantage of the method proposed is the fact that the water-polymer influence on the reservoir bed is in accordance with the existing method of developing most deposits in the South-West of Yakutia. However, it should further be necessary to built additional units for dosing chemicals, either directly at the deposit in the form of a stationary object, or in the form of mobile cluster systems. A preliminary calculation of the cost-effectiveness of the technological solution proposed was made at the example of the Irelyakh Gas-and-Oil deposit. Thus, in order to calculate economic efficiency, the following conditions and assumptions were adopted: the amount of crude oil in the Irelyakh deposit is 61 thousand tons per year, the annual volume of injected displacement agent is 88 thousand m^3. In case of using highly mineralized solution (HMS), the oil recovery factor (ORF) is comparable with the value obtained in laboratory, and it is 40%. Based on this fact, we can assume that introduction of the polymer

flooding method will increase the amount of recovered oil to 93 thousand tons of oil, since when it is used as oil displacement agent with PEG solution with concentration of 30 g/l, ORF will be 61%, and to 103.7 thousand tons of oil in case of ORF at 68% for CMC solution with concentration of 5 g/l. With that, it is likely that with increasing oil recovery factor, the rate of oil recovery will increase proportionally to its increase (Table 2), since when the injected agent is replaced, its volume does not change.

However, in order to substantiate the use of the polymer flooding method, the expected technological effect manifested in additional delivery of oil and incresed ORF, is not enough. It is necessary to calculate cost-effectiveness on the basis of comparing incurred cost of the basic variant and development using water-soluble polymers. In order to calculate cost-effectiveness of using polymer solutions, mineral replacement tax, oil production costs have been taken into account, including the cost of purchasing and transportation of polymers. Thus, the cost of one ton of CMC and PEG is equal and it is 52 thousand rubles (Dzerzhinsk). The required amount of displacement agent per year is 88 thousand m^3, i.e., in case of using PEG solutions with concentration of 30 g/l, 2638 tons of the polymer are required, and in case of using CMC at concentration of 5 g/l, 439.7 tons of the polymer are required, thus costs of purchasing and transportation of PEG would be approximately 39.6 million rubles, while the price forpurchasing and transportation of CMC would be 6.6 mln. rubles. The estimated profit, including all costs of oil production, in case of using PEG solution with concentration of 30 g/l as the displacement agent will be 209.0 million rubles, and in case of using CMC solution with concentration of 5 g/l - 400.5 million rubles, while in case of using HMS as oil displacement agent, the profit is 252.7 million rubles at oil price of 11 thousand rubles per 1 ton.

CONCLUSION

So, the calculations showed that the use of PEG solutions with concentration of 50% would be unprofitable, since the costs of the activity and oil production exceeds the revenue from selling the produced oil. The use of PEG solutions with concentrations of 20 and 30 g/l, if compared to highly mineralized solution, does not give a positive result due to high cost of solutions preparation, economic efficiency is 70 and 17 % less, respectively, compared to HMS.

Most cost-effective method in conditions of deposits with low reservoir temperatures and high mineralization of reservoir water is the use of CMC solutions, which will also increase economic efficiency of oil production by 33-58 % (Table 2). Thus, in order to improve the flooding method in deposits of southwestern Yakutia, it is recommended, according to comprehensive research, to use carboxymethylcellulose solution at a concentration of 5 g/l as the base displacing agent.

For the first time, for the complex of oil deposits in the Nepsk-Botuobaanteclise, a new approach is recommended to solving the problem of increasing oil recovery through the use of optimally accessible technology that makes it possible to ensure consistently high levels of oil recovery and to reduce the actual cost of hydrocarbons production.

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