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THE USE OF OIL-SOLUBLE POLYMERS TO ENHANCE OIL RECOVERY IN HARD TO RECOVER HYDROCARBONS RESERVES

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ABSTRACT

Currently, the share of new fields in many places over the world, which are at the initial stage of development, is constantly growing.

Fields often have a complex heterogeneous structure with hard-to-recover reserves, therefore, for their effective development, it is necessary to use completely new approaches, including improving existing methods of enhanced oil recovery.

In this work, experimental verification of a new technology using oil-soluble polymers and comparing it with technology based on the use of water-soluble polymers has been performed. In laboratory conditions, a new technology for polymer flooding at an early stage of development using oil-soluble polymers was developed and experimentally confirmed. The new technology has made it possible to increase the degree of reserves recovery by an average of 30% compared to existing methods of enhanced oil recovery and to solve a number of problems arising from the use of water-soluble polymers. Such problems are the freezing of aqueous polymer solutions in winter and the poor solubility of polymers in formation waters with a high salt content. The use of new technology can also reduce energy costs by 25%.

Keywords: Polymers, EOR, Solubility, RF , Oil viscosity, Water cut, Sweep efficiency.

I. INTRODUCTION

At present and in the near future, one of the main problems of energy supply in the world is enhanced oil recovery [1][2][3][4]. In spite of the high-tech development, the oil recovery methods currently used in the fields, in some oil countries, allow achieving an oil recovery factor (RF) in the range of 0.25–0.43, which is an unacceptable indicator.

The remaining reserves that are not recovered by existing and industrially developed extraction methods reach approximately 57-75 % of the original geological oil reserves in the subsurface. Hence, they represent a large reserve for increasing recoverable resources using enhanced oil recovery methods [5][6][7][8].

Many of the hydrocarbons fields, in different places, are currently at the second or third stages of development, which are characterized by a high water cut of the well production due to significant depletion of reserves [9][10][11]. The low degree of recoverability of oil reserves, not involved in a reservoir development is determined by the low permeability of the reservoir and high layer-by-layer heterogeneity along the section of the productive formation [12][13][14]. Geological and field studies show that as a result of the formation of technogenic fracturing, uncontrolled and unproductive fluid circulation occurs, which is one of the reasons for the premature flooding of production wells, and also contributes to the formation of zones not involved in the development [15][16][17].

Polymer waterflooding allows increasing the reservoir sweep efficiency due to a decrease in the mobility of the oil-displacing fluid [18][19][20]. In addition, this method is relatively cheap and therefore it has become widespread in the fields. Polymer flooding can increase oil recovery by about one and a half time [21][22][23]. However, this method of enhanced oil recovery has a number of disadvantages [24][25][26]:

- Insignificant effect of injection of a polymer solution into a homogeneous reservoir with low-viscosity oil;
- Low efficiency at a late stage of development;
- The final result depends on the composition and amount of salts in the reservoir waters used as the oil displacement fluid. A sharp decrease in the efficiency of polymer solutions in conditions of high

mineralization is due to the fact that during preparation and contact with reservoir waters, the oil-displacing capacity decreases due to the precipitation of the polymer;

- The impossibility of using aqueous solutions of polymers at low ambient temperatures due to their freezing.

II. EXPERIMENTAL PART

The last above two mentioned points have the greatest influence on technical and economic indicators [27][28][29]. To reduce the negative effect, it is necessary to significantly increase the concentration of the polymer solution, and at low temperatures to heat the solution. This, in turn, reduces the viscosity of the solution, as can be seen from Fig. 1, and leads to the need to increase the concentration of the solution, i.e., increase the cost of the injected fluid[30][31]. In this case, thermal destruction of the polymer is also observed and the effectiveness of this method decreases.

To solve the above problems, the water-soluble polymer can be replaced by an oil-soluble one, which is not affected by high salinity of formation water and does not freeze at low temperatures, and it is also soluble in any hydrocarbon liquid, including oil.

To verify the replacement of one polymer with another, a series of experiments was carried out on the SAP 700 laboratory unit with two bulk columns [32][33][34]. The oil displacement unit was modeled and compared using the slugs of polymer solutions of different physical and chemical nature. In the first and second experiments, the slug was a solution of polyacrylamide (PAM) in water, and in the third experiment, the injected slug was a solution of polyhexene (PH) in oil. The unit can be used for simultaneous flow of fluid with a viscosity (μ) through two parallel columns with different permeability (k), which makes it possible to simulate a heterogeneous reservoir. The basis for the simulated medium was formation fluids taken from an oil field and quartz sand with different fractions in the range of 0.05-0.25 mm.

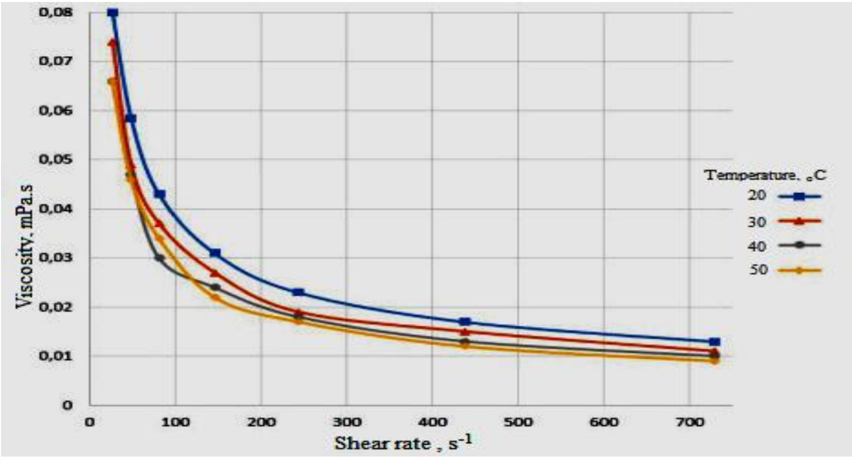

Fig.-1: Dependence of the viscosity of an aqueous solution of polyacrylamide on the shear rate at different temperatures.

Many works have made an assumption about the low efficiency of polymer flooding at a later stage of the field development [35][36][37]. We carried out a basic experiment, during which a field was simulated with interlayers, the permeability of which was significantly different and amounted to 1.392 and 0.355 μm^2, respectively. At the initial stage, displacement occurred due to water injection, and then after the water breakthrough and a decrease in oil production, a slug of an aqueous PAM solution with a volume of 18.7 ml (27.3% of the total pore volume of the two columns) was created, which eventually allowed to achieve an oil recovery factor of 70.2% and 17.2% for the high and low-permeable part of the reservoir, respectively.

During the second experiment, a field was modeled with permeability layers of 1.343 and 0.343 μm^2, respectively. The initial oil saturation of the high-permeable part was 32.6 %, and the oil saturation of the low-permeable part of the reservoir was 32.5 %. At the initial stage of flow (without preliminary pumping of water), a slug of a polyacrylamide solution with a volume of 18.9 ml (24.3% of the total pore volume) was created with a dynamic viscosity of an aqueous polyacrylamide solution of 35 mPa .s, as in the first experiment. After the

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introduction of the polymer slug, oil displacement from both columns was continued with subsequent water injection. The results of this experiment are shown in Fig. 2.

III. RESULTS AND DISCUSSION

Fig. 2 shows that the flow rate through the highly permeable part of the formation, in accordance with Darcy's law (Eqt. 1), is significantly exceeding the flow rate through the low-permeable part. Therefore, at the first stage, there is a significant increase in the recovery factor of the 1st column compared to the recovery factor of the 2nd column.

$$Q = \frac{k.\Delta P}{\mu.L} \quad (1)$$

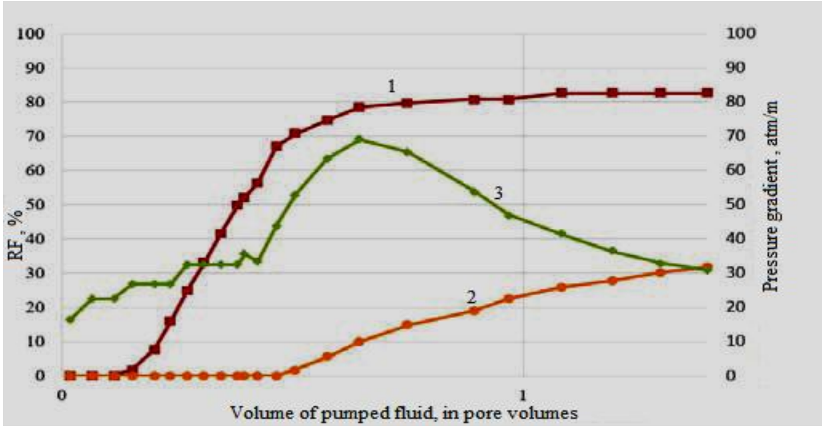

Fig.-2 : Dependence of the pressure gradient and the oil recovery factor (RF) on the volume of the pumped fluid with the PAM slug, introduced at an early stage: 1 - RF 1(high permeable zone) ; 2 - RF 2 (low permeable zone); 3 - Pressure gradient

The result obtained indicates the need to increase the dynamic viscosity (μ) of the polymer solution slug. During the second experiment, the oil recovery factor of 80.6% was achieved for the high-permeable part of the reservoir, i.e. 10.4 % more than when the polymer slug was introduced at the late stage (the first experiment), and increased to 32.1% for the low-permeable part, which is 14.8% more than in the baseline experiment. There was also a significant increase in the anhydrous oil production period. In the case of polymer flooding carried out at a late stage (first experiment), RF was 24.6% of the total pore volume. With polymer flooding at an early stage (the second experiment), a result of 51.1 % was obtained, i.e. the period of oil production before the appearance of water increased by 2 times.

In the third experiment, the SAP 700 unit simulated a field with two interlayers with reservoir properties similar to the first and second experiments. The permeability of the simulated first and second interlayers is different and amount to 1.305 and 0.396 μm^2, respectively. The interlayers were pre-saturated with oil, and their initial oil saturation was 34.6 and 31.7 %.Then a slug of 11.2 ml oil-soluble polyhexene (PH) solution was created (18% of the total pore volume of the interlayers), the dynamic viscosity of which was 30 mPa . s. The slug of the PH polymer solution was created in a smaller volume based on economic indicators. After the formation of polymer slugs of the PH solution at the inlet of both interlayers, water began to displace them. At the end of this stage, the oil displacement ratio was 70.9 and 78.4% for high and low permeability interlayers, respectively (Fig. 3). Thus, there was a decrease in the RF 1 of the high-permeable interlayer by 9.7 %, but there was an increase in the RF 2 for the low-permeable part of the formation by 46.4% compared to the average result with a slug made of an aqueous PAM solution (the second experiment). Although there was a slight decrease in the final oil RF for the high-permeability column, due to the equalization of flow rates through both interlayers, the fluid flow was more evenly through the high-permeability and low-permeability parts of the formation and this led to a significant increase in the total recovery of reserves.

Fig. 3 also shows that after the injection of the PH solution slug and subsequent displacement by water, an increase in the pressure gradient is observed, which indicates the beginning of flow through a low-permeability interlayer. But in contrast to the studies with a slug made of an aqueous PAM solution (Fig. 2), this stage begins twice as early, namely at the time when the flow rate of the high-permeable interlayer has not reached the maximum value and there is no water breakthrough through the high-permeable interlayer. At the same time, a significant increase in the flow rate of the low-permeability interlayer is observed in comparison with similar experiments with aqueous solutions of PAM. This fact makes it possible to simultaneously reach the limit of profitability in terms of the water cut of each interlayer, and also allows to reduce the development time of the field and not to use technologies for isolating high-water cut interlayers in order to extract residual oil from low-permeability interlayers. It should also be noted that the pressure gradient over the entire development period with the use of oil-soluble PH decreased by 15% compared to the pressure gradient when using an aqueous PAM solution. This leads to an additional positive economic effect from the use of this technology.

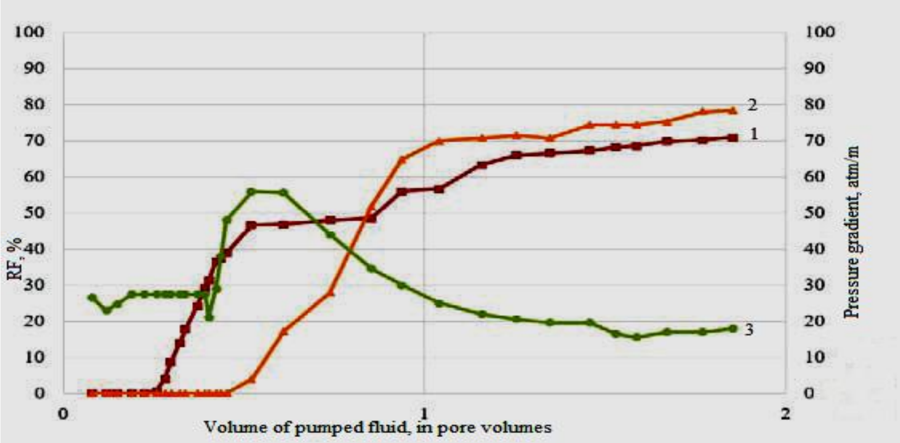

Fig.-3: Dependence of the pressure gradient and the oil recovery factor (RF) on the volume of the pumped fluid with the PH slug, introduced at an early stage: 1 - RF 1; 2 - RF 2; 3 - Pressure gradient

From a comparative illustration of the results of three conducted experiments, it can be seen (Fig. 4) that with the traditional introduction of the PAM slug at a late stage, almost all the fluid flow goes through the highly permeable part of the formation, from which oil is intensively displaced. But then this leads to negative consequences, since further displacement by water makes it possible to achieve less than 50% of the total oil recovery factor (RF) from two columns. The introduction of polymer flooding at the initial stage initially gives a smaller increase in the production of reserves, but at the same time has a positive trend towards an increase in the rate of production and, as a consequence, a greater increase in the final oil recovery factor.

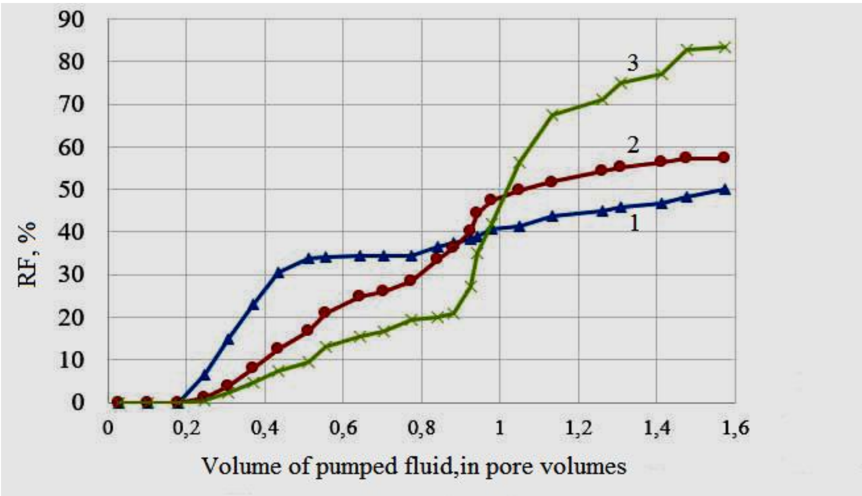

Fig.-4: Dependence of the RF on the volume of pumped fluid: 1 - PAM at a late stage; 2 - PAM at an early stage; 3 – PH at early stage

It also follows from Fig. 4 that the use of an oil-soluble PH polymer at an early stage of development in comparison with a water-soluble PAM allows achieving a greater final effect. This made it possible to fix the indicators of the final oil recovery factor at around 83%, which is 27% more than with a similar technology with a slug of water-soluble PAM polymer.

IV. CONCLUSION

Thus, on the basis of the experimental data obtained, it can be concluded that the use of a viscous and non-freezing slug of an oil-soluble polymer not only solves the problem of incompatibility with formation waters that arise in water-soluble polyacrylamide, but also turns out to be more effective for leveling the displacement front.

The predicted result of using this technology will be an increase in oil recovery by about 30% while reducing energy costs by 25%.

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