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Тема работы
Оценка полимерного заводнения применительно к неоднородным карбонатным коллекторам Пашкинского месторождения Оренбургской области

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Содержание

Аннотация

Объектом исследования является процесс технологии полимерного заводнения с применением поверхностно-активного вещества и щелочи применительно к карбонатным гетерогенным коллекторам Пашкинского месторождения. Целью этой работы является изучение процесса полимерного заводнения с добавлением ПАВ и щелочи на данном месторождении, изучение влияния каждого компонента отдельно на процесс вытеснения нефти, выбор объектов под закачку полимера, ПАВ и щелочи в соответствии с геолого-физическими критериями, основанные на практическом опыте. Основной целью работы является определение эффективности применения данной технологии на ПАшкинском месторождении. Задача проекта осложняется наличием карбонатных коллекторов, многопластовой залежи, высокой неоднородности пласта.

В процессе исследования были рассмотрены разные режимы закачки полимера и ПАВ в симуляторе на гидродинамической модели Пашкинского месторождения. Наиболее эффективные режимы закачки были выбраны для расчета экономической прибыли по каждому варианту, полимерному и ПАВ-полимерному заводнению.

В результате исследования был выявлен наиболее выгодный вариант заводнения, используя экономических расчетов. После этого, анализ влияния анизотропии был проведен.

Основные конструктивные, технологические и технико-эксплуатационные характеристики: программное обеспечение Schlumberger симулятор ECLIPSE100, используемый для моделирования закачки полимера и ПАВ.

Степень внедрения: технология полимерного заводнения с добавлением ПАВ и щелочи является широко применяемой и изучаемой во всем мире. Однако, большее количество проектов с данной технологией внедряется за рубежом. В России данная технология начинает внедряться на сегодняшний день на Западно-Салымском месторождении.

Область применения: технология полимерного заводнения может применяться на месторождениях с определенными геологическими условиями и петрофизическими параметрами, диапазон которых выявляется опытом месторождений-аналогов.

Экономическая эффективность данной работы была рассчитана для полимерного и ПАВ-полимерного заводнения. В результате рассчетов был определен вариант с полимерным заводнением как наиболее эффективный.

В будущем планируется наиболее обширное исследование полимерного заводнения в карбонатных коллекторах, так как эти коллектора представляют большую сложность и неопределенность в применении данной технологии из-за наличия трещин и каверн.

Annotation

The object of this study is polymer flooding process technology with a surfactant and alkali applied to carbonate reservoirs of Pashkinskoe field. The aim of this work is to study the process of polymer flooding with the addition of surfactants and alkalis in this field, the study of the effect of each component separately in the process of oil displacement, the choice of objects for injection of the polymer, surfactant and alkali according to the geological and physical criteria, based on practical experience. The main purpose of the work is to determine the effectiveness of this technology in the field Pashkinskoe. The project's objective is complicated by the presence of carbonate reservoirs, multizone, high reservoir heterogeneity.

The study examined the different modes of the polymer and surfactant injection in the simulator. The most effective injection modes were selected to calculate the economic benefits of each option, polymer and surfactant-polymer flooding.

The study has been identified the most profitable option flooding using economic calculations. Then, the influence of anisotropy analysis was performed.

The basic constructive, technological and technical and operational characteristics: Schlumberger software simulator ECLIPSE100, used to simulate the injection of polymer and surfactant.

Degree of implementation: the technology of polymer flooding with the addition of surfactants and alkalis is widely used and studied worldwide. However, a greater number of projects with this technology is being implemented abroad. In Russia, this technology is beginning to be introduced today in the West Salym field.

Scope: The technology of polymer flooding can be used in fields with specific geological conditions and petrophysical parameters, which range detected experience fields peers.

The cost-effectiveness of this work was calculated for the polymer and surfactant-polymer flooding. As a result of calculations was defined option polymer flooding as the most effective.

In the future, the most extensive study of polymer flooding in carbonate reservoirs is planned, since these reservoirs show great complexity and uncertainty in the application of this technology due to the presence of cracks and cavities.

Введение

Полимерное заводнение (ASP) с применением щелочи и поверхностно-активного вещества - это сложный химический процесс, который включает в себя добавку щелочи, поверхностно-активного вещества и полимер в одной оторочке, направленная на повышение нефтеотдачи. В настоящее время ASP процесс широко изучается во всем мире и является многообещающим благодаря синергии этих трех компонентов. В большинстве случаев этот процесс исследуется в обломочных коллекторах. Исследования этого заводнения в карбонатных коллекторах являются редкими и имеют отличительный характер по сравнению с процессом в обломочных пород.

Карбонатные коллектора – это гетерогенные образования, которые усложняют применение технологии полимерного заводнения с добавлением щелочи и ПАВ. Целью технологии является увеличение коэффициента извлечения нефти, снижения проявления эффекта языкообразования, повышение эффективности вытеснения нефти, а также снижение остаточной нефтенасыщенности. Проблемы, существующие в этой области: высокая стоимость, отсутствие глубокого понимания процесса, технологические риски, потери химических веществ во время заводнения.

Основными целями этой работы являются представление критериев отбора объектов для химического процесса увеличения нефтеотдачи, рассмотрение возможности применения данной технологии в карбонатном коллекторе, изучение влияния поверхностно-активного вещества и щелочи для вытеснения нефти и исследование профиля добычи нефти и остаточной нефтенасыщенности во время ASP заводнения. Целью данного исследования является определение эффективности технологии ПАВ-полимерного заводнения на Пашкинском месторождении. Задача проекта заключается в оценке эффективности этой технологии при наличии карбонатных коллекторов, многопластовой залежи, высокой неоднородности пласта. Для решения данной проблемы необходимо понять технологию процесса заводнения, в том числе поведение каждого компонента данной технологии в карбонатном коллекторе. Также необходимо выбрать объекты для использования технологии с использованием геолого-технологических критериев и выбрать оптимальные режимы закачки компонентов ASP технологии и рассчитать экономический эффект.

В качестве входных параметров были представлены результаты лабораторных экспериментов, гидродинамическая модель с базовым вариантом разработки без полимеров, щелочи и ПАВ, свойства пластовых флюидов, описание керна, гидродинамические и полевые геофизические исследования, а также общая информация о месторождении.

5. Polymer flooding

One obvious mechanism in polymer flooding is the reduced mobility ratio of displacing fluid to the displaced fluid so that viscous fingering is reduced. When viscous fingering is reduced, the sweep efficiency is improved. When polymer is injected in vertical heterogeneous layers, crossflow between layers improves polymer allocation in the vertical layers so that vertical sweep efficiency is improved.

There are two main polymer types such as hydrolyzed polyacrylamide (HPAM) and biopolymers. Natural polymers are less used. Quality polymer should have the following properties:

- negative ionic hydrophilic group to reduce adsorption on rock surfaces
- good viscosifying powder
- nonionic hydrophilic group for chemical stability.

5.1. Shear rate

It is known that at high shear rates (pumping rates) polymer solution may be subjected to degradation, while the molecular weight is decreased and, accordingly, the viscosity of the solution. Also at a high shear rate polymer network structure is damaged and viscosity is reduced. When shear rate decreases network structure is restored and viscosity back up again.

That means at a high shear rate, the associating polymer network structure was damaged and the viscosity was significantly reduced. When the shear rate was reduced, the network structure was restored, and the viscosity was back up again. This shear reversibility is very beneficial in enhanced oil recovery field applications because it improves the well injectivity due to the shear thinning effect at the perforation and near the wellbore. Flow velocity is reduced and viscosity is restored far away from a well. It was found that the viscosity after shearing was higher than that before shearing [1].

5.2. Temperature Effect

Researchers reported that at a low shear rate the polymer solution viscosity decreases with temperature according to the Arrhenius equation:

$$\mu_p = A_p \exp\left[\frac{E_a}{RT}\right],$$

where

Ap - frequency factor

Ea - the activity energy of the polymer solution

R - universal gas constant

T - absolute temperature

This equation shows that the viscosity decreases sharply when the temperature increases.

The activity of polymer chains and molecules is increases with temperature and it lead to reducing friction between molecules reducing the flow resistance. Hydrolyzed polyacrylamide has two Eas. When the temperature is less than 35°C, Ea is low and the viscosity does not change too much with temperature. When the temperature is higher 35°C, Ea is high, and the viscosity is more sensitive to temperature [1].

5.3. Chemical stability

Chemical degradation is related to the destruction of polymer molecules through short-term attack by contaminants such as oxygen and iron or through longer-term attack to the molecular backbone by processes such as hydrolysis that is caused by the intrinsic instability of molecules even in the absence of oxygen.

Thus, polymer chemical stability can be controlled by oxidation-reduction reactions and hydrolysis.

The effect of oxygen on HPAM solution viscosity is not significant at a low temperature and the polymer solution could be stable for a long time. As the temperature increases polymer solution viscosity quickly decreases with time. Therefore, the amount of oxygen in the solution should be minimized by using oxygen scavengers in order to protect the polymer from any further oxygen ingress into the solution [1].

5.4. Mechanical and biological degradation

Mechanical degradation means the destruction of molecules in the region of high flow rate close to a well as a result of high mechanical stresses on the macromolecules. This effect is essential only in the reservoir near the wellbore. Mechanical degradation of polymer is much more severe at higher flow rates, longer distances, and lower brine permeabilities. In a lower-permeability porous medium, the pore throat diameter is smaller, and the stress acting on the polymer is larger. Thus, polymer chains can be broken and the viscosity is reduced. Maerker (1975, 1976) noted that the mechanical degradation of the polymer was more severe in higher salinity brines and the presence of calcium ions (Ca2+) has particularly damaging effect.

Biological degradation is related to the microbial destruction of macromolecules of polymers by bacteria during storage in the reservoir. Despite of the problem is more common for biopolymers, biological degradation may also occur in synthetic polymers. It has been found that polymer can provide nutrition to sulfate reducing bacteria. With increasing SRB, polymer viscosity decreases [2].

5.5. Polymer retention

Polymer retention is related to adsorption, mechanical trapping, and hydrodynamic retention. Mechanical trapping and hydrodynamic retention can occur only in flow-through porous media. Mechanical entrapment depends on the pore size distribution. This mechanism is more likely for polymer retention in low-permeability formation. If the trapping process acts on polymer molecules in the range of average pore size, it will lead to material accumulation close to the injection well which gives an exponential penetration profile into the formation. This will lead to pore blocking and well plugging. That is the polymer flood should be used in a high permeability formation.

Adsorption is a process of the interaction between polymer and the solid surface. During interaction polymer molecules is bounded to the surface of the solid, mainly by van der Waals forces and hydrogen bonding. Adsorption depends on the surface area exposed to the polymer solution and it is the only mechanism that removes polymer from the bulk solution.

Application of prefiltering or preshearing and application of polymer in high permeable formations can help to avoid mechanical entrapment. Compared with alkaline and surfactant, polymer mechanical trapping and hydrodynamic retention are more significant because of large molecules.

Li (2007) observed that the adsorption of a hydrophobically associating water-soluble polymer did not follow the Langmuir-type isotherm. Figure 5.1 shows that the adsorption increased to a maximum value and then decreased with polymer concentration increasing. The reason is probably that the hydrophobic polymer has an adsorption layer of multiple molecules on rock surfaces. As concentration is increased, the adsorption layer becomes thicker. When the polymer concentration is further increased, the molecular interaction in the liquid is stronger than between the adsorbed molecules and rock surfaces. Therefore, the adsorbed molecules may leave the rock surface and redissolve into the liquid that lead to adsorption decreases [2].

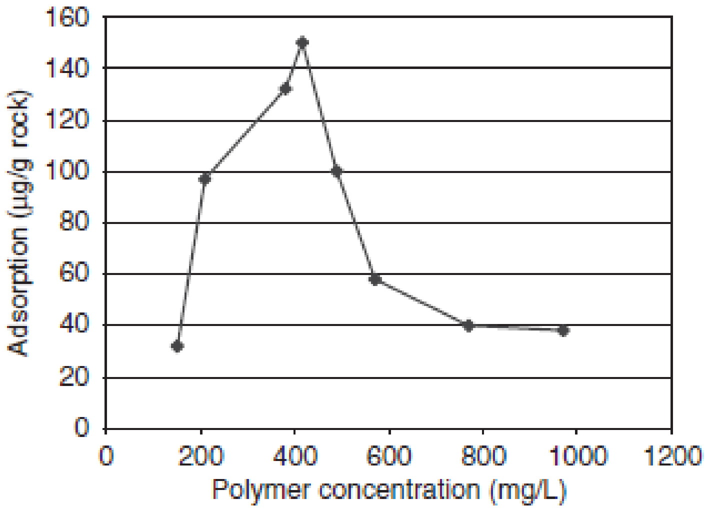


Figure 5.1. Polymer adsorption on Daquing sand

5.6. **Permeability reduction**

As discussed above polymer adsorption causes permeability reduction or pore blocking. Therefore, rock permeability is reduced during injection of polymer through it, compared with the permeability when water is injected. This permeability reduction is defined by the permeability reduction factor (Fkr):

(2)

$$Fkr = \frac{\text{Rock perm.when water flows}}{\text{Rock perm.when aqueous polymer solution flows}} = \frac{\text{Kw}}{\text{Kp}} \quad (2)$$

Bondor et al. (1972) assumed that the permeability reduction is caused by polymer adsorption, and the adsorption process is irreversible. It was assumed that the maximum permeability reduction corresponds to the polymer adsorptive capacity on the rock. Fkr,max decreases with increasing permeability, which is consistent with the observation that the polymer retention decreases with permeability [3].

5.7. **Relative permeabilities in polymer flooding**

It is known that polymer flooding does not reduce residual oil saturation. The polymer is used for increasing displacing fluid viscosity and increasing sweep efficiency. It is also noted that fluid viscosities do not affect relative permeability curves. Therefore, the relative permeabilities in polymer flooding and in waterflooding after polymer flooding are the same as before polymer flooding if we take into account the resistance factor for the k_{rw} in polymer flooding and the residual permeability reduction factor for the k_{rw} after polymer flooding. This statement has been supported by some experiments.

Schneider and Owens (1982) conducted experiments in order to determine the effect of polymer on relative permeability in which polymer solution was injected into a reservoir at waterflood residual oil saturation. All the tests were conducted with polyacrylamides in water-wet cores. The relative oil permeability was unaffected by the polymer flow. The relative permeability curve for polymer solution was significantly lower than the corresponding relative water permeability curve before polymer contact of the core. Relative permeability curves were also determined for the displacement of oil by water. Figure 5.7.1 compares the relative permeability for the oil and water phases before (with the subscript l) and after (with subscript p) polymer contact. RRF in the figure denotes Fkrr in the text. In this test there was little difference between the residual oil saturations obtained before and after polymer flooding. The relative water permeability after polymer contact, krwp, was reduced significantly compared with the relative water permeability before polymer injection, $k_{rw}1$. The parallelism of $k_{rw}1$ and k_{rwp} is explained by the fact that the reduction in water relative permeability was caused by the permeability reduction due to polymer adsorption. Polymer adsorption occurs only in the pore networks transporting the aqueous phase [1].

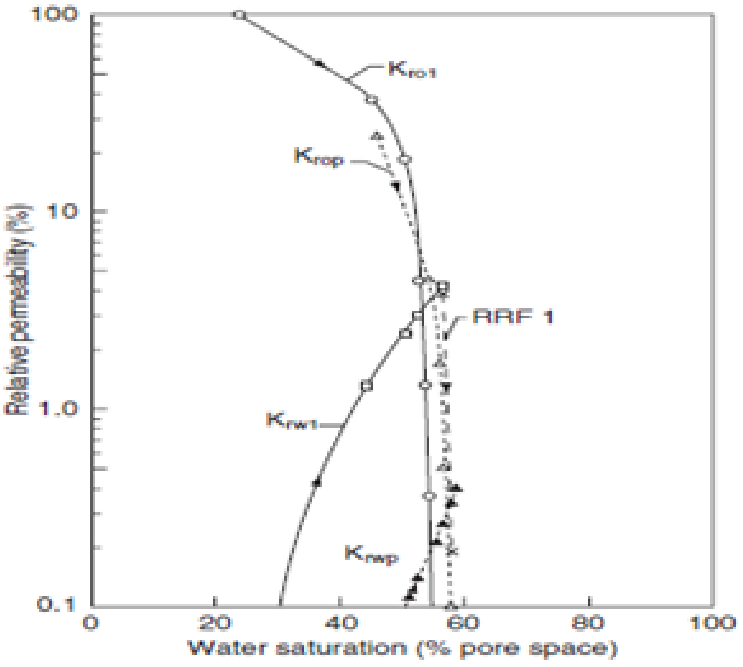


Figure 5.7.1. Water/oil relative permeability before and after contact with polymer

There are several reasons as summarized here:

- Polymer is soluble in water phase but not in oil phase. When polymer solution flows through pore throats, high molecular weight polymer is retained at the throats. Then the polymer blocks water throats and k_{rw} is reduced.
- Polymer molecules can form a hydrogen bond with water molecules; this capability enhances the affinity between the adsorption layer and water molecules. Rock surfaces become more water-wet and k_{rw} is reduced.
- Polymer and oil have segregated flow paths. Therefore, polymer reduces k_{rw} but not k_{ro} (Liang et al., 1995) [1].

5.8. Displacement mechanism in polymer flooding

One of the results of polymer flooding is the reduced amount of water injected and produced. Since polymer solution improves mobility ratio and sweep efficiency, less water is required for injection and less water is produced. Polymer is also used to block water channeling through high-permeability layers and water conning from bottom aquifers. There is limitation for the water volume injected due to high injection pressure or blocking water channeling or water coning. This may cause that water will bypass the injected polymer zone and crossflow to high permeability zones or to the producing wellbores. To avoid this kind of problem, a weak gel that has high resistance to flow but is able to flow can be injected deep into reservoir. Thus, a large volume or large area of polymer zone is formed to block water thief zones or channels. In polymer and gel treatment, another mechanism is called disproportionate permeability reduction (DPR). Through the use of this mechanism, polymer and gel can reduce water permeability much more than oil permeability [4].

5.9. The results of investigations of polymer samples

In conditions of the Pashkinskoe field selection of polymer was conducted carefully because during filtration of the polymer solution with large molecule in the formation with low values of porosity and permeability, increase pressure on the well can occur and also decreasing viscosity due to mechanical destruction of polymer. For selection of polymer brand molecular characteristic of polymer samples were investigated that are presented in the table 5.9.1.

Table 5.9.1- The results of investigations of sample molecular characteristics

Polymer brand	The intrinsic viscosity, dl/g	Molecular weight, mln	Degree of hydrolysis, %
AN 132	20,3	14,1	8,5
FLOPAAM 3630S	23,8	15,9	25,6
FLOPAAM 1630S	26,2	23,2	8,1
FLOPAAM 5115 VHM	19,0	12,2	9,6
Superpusher K 129	22,1	16,7	7,7
FP-5205 VHM	24,9	19,1	16,8
FA 920	11,4	5,0	1,0
FA 920 VHM	17,3	11,2	1,0
AN 910 VHM	20,9	15,0	8,0
AN 912 VHM	16,9	10,5	2,1
Praestol 2515 KI	Praestol 2515 KI	Praestol 2515 KI	Praestol 2515 KI

It is known that for polymer flooding polymers with high molecular characteristics (molecular weight and degree of hydrolysis) are more effective since its viscosity is higher than viscosity of polymers with low molecular characteristics even at the same concentration.

Degree of hydrolysis affects solubility in water, viscosity and retention. Polymers with high degree of hydrolysis are sensitive to mineralization and hardness of water (Ca and Mg) and can subject to salting. Polymers with low degree of hydrolysis are badly soluble in water. Therefore selection of polymer was based on the optimization of these properties.

As regards molecular weight with increasing molecular weight of the polymer, thickening ability of the composition increases but at the time resistance to degradation decreases. Therefore, when choosing polymers limited molecular weight range was chosen 8 - 16 mln.

In order to determine ability of polymer solution to filtrate in porous medium it is necessary to eliminate pore size and evaluate polymer molecule size with certain molecular weight.

Average pore size on rock can be established from Kozeny equation:

$D_{av} = 2 \cdot \sqrt{8 \varphi k / m}$, where (2)

Dav – average pore diameter;

φ – tortuosity of pore space;

k – permeability;

m – porosity

The radius of the helical molecules polyacrylamide is a function of the molecular weight of the polymer and can be estimated from the Einstein equation:

$R_м = (30M \cdot [\eta] / \pi A)^{1/3}$, $D_м = 2 R_м$, where

$R_м$ – radius of the helical molecules, cm

M – molecular weight of polymer, g/mole

A – number Avogadro, $6{,}022141 \cdot 10^{23}$, $моль^{-1}$

$[\eta]$ – the intrinsic viscosity, cm^3/g

Calculation showed that molecule sizes of chosen polymers have values lower than pore sizes in the formation. Therefore, it can be noted that these solutions will filtrate into carbonate formation of the field P. However, with increasing polymer concentration intermolecular interactions, formation of associates leading to enlargement can occur.

The individual particles of polymer powder and pores are close to spherical in shape, most of the particles have a diameter in the range 0.2-0.4 mm. The presence of larger particles increases the dissolution of the polymer. In the laboratory conditions water wets the exterior surface of the particles. Polymer swelling is quite slow due to the low polymer with the solvent of the contact surface. The penetration of the solvent on the pore channels is complicated because of the opposition of capillary forces.

In real conditions the polymer particles in the form of a polymer slurry fall rapidly enough to the pump suction and the high pressure line. Pressure almost instantaneously rises from atmospheric to a few tens kg/cm^2. With this pressure differential capillary force is suppressed, and the water fills the channels of the polymer particles, reducing the time of dissolution of the polymer.

The results of investigations are presented in the figure 5.9.1 and show that all samples are soluble in the injected water of the field P during about 1 hour anf have low insoluble residue

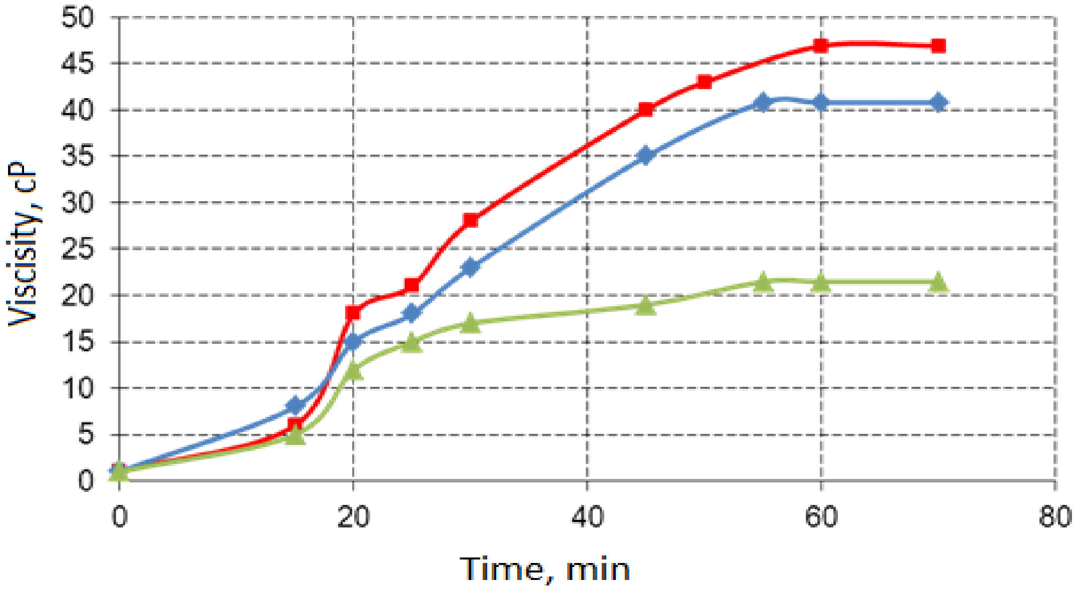


Figure 5.9.1. The kinetics of dissolution of the polymer in the injected water

Investigations of viscous characteristics of polymer solution polyacrylamides were conducted under simple shear flow in the void volume with using a rotary viscometer. These researches were carried out using range of shear rates 0,122 – 122,0 sec^{-1}. Viscosity of polymer solutions is affected by molecular characteristics, concentration, mineralization and temperature.

For comparing thickening ability of different polymer brands reagent tests were conducted under the same conditions at 28°C. The results of the test of viscosity versus shear rate polymers are presented in Table 5.9.2.

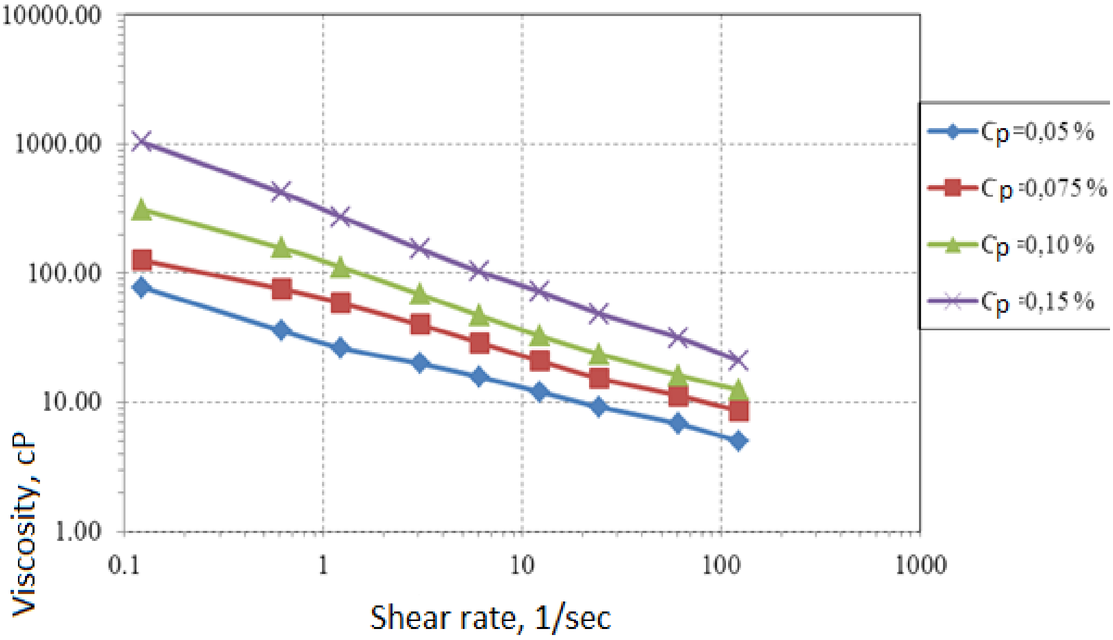
Table 5.9.2. Rheology of polymer solution

Shear rate, sec^{-1}	Dynamic viscosity, cP		
	FLOPAAM 3630 S	FLOPAAM 5115 VHM	Praestol 2515 KI
0,122	312,00	216,00	66,00
0,612	157,20	118,80	38,40
1,223	111,60	88,20	31,80
3,058	68,40	57,60	26,40
6,115	46,92	40,80	21,48
12,23	32,70	29,22	17,34
24,46	23,61	21,57	13,74
61,15	16,20	15,00	9,91
122,3	12,5	11,5	8,1

Solvent – injected water of the field P, Cp=0,1%; t=28°C

Studies show that at the same concentration of polyacrylamide difference in viscosity of the solutions in different samples is observed, which depends on the technology of the polymer, its molecular weight and degree of hydrolysis. As seen from the above data, the viscous properties of the solutions directly correlated to their molecular characteristics. The larger the content of polymers and macromolecules in which the charged carboxyl groups are present, the greater the thickening ability of the polymer.

Polymer FLOPAAM 3630 S has the highest thickening ability. For this polymer rheological studies on determination of dependence of the viscosity versus solution concentration in the range 0.05-0.15% were conducted [5].



mineralization 0,5 g/l; $t=28^oC$

Figure 5.9.2. The rheology of polymer solutions FLOPAAM 3630S

5.10. Study of resistance to degradation of the polymer solutions

It is known that at high shear rates polymer solution can subject to destruction leading to decreasing molecular weight and viscosity. Testing the ability of the polymer solution to resist mechanical degradation with selected polymer samples was conducted. Resistance to mechanical degradation is characterized by mechanical durability factor (D) which is determined as ratio of solution viscosity degraded and initial viscosity. Prepared polymer solutions with concentration 0.15% pumped through the core at a rate realized in the near wellbore of injection wells. In the experiments the front velocity was assumed to be 150-200 m/day.

Experimental data of viscosity change of solutions as a result of mechanical destruction are presented in the table 5.10.1.

Table 5.10.1 Mechanical destruction of polymer

Brand	Viscosity, cP		The degree of resistance to mechanical degradation, rel.unit
	Initial	Destructed	
FLOPAAM 3630 S	102,6	82,9	0,81

$(C_p=0{,}15\%;\ j=6{,}1\ sec^{-1};\ T=28^oC)$

The degree of resistance of the test polymer solution to the destruction of 0.81 relative units, which meets the requirements for polymers.

Based on studies conducted for conditions field P it is recommended for further research grade polymer FP-S 3630 at a concentration 0,05-0,075% for injected water [5].

5.11. Surfactant-Polymer flooding

Since the polymer does not interact with oil, its macromolecules do not affect the mobility of oil. When oil is displaced by the polymer solution upon mineralized water in combination with junction of surfactant transition of active substance from the aqueous phase into the oil occurs, thereby improving the rheological properties of the residual oil and its mobility. On the other hand, under the influence of surfactants structural changes of polymer macromolecules occur and improving rheological properties, leading to a further reduction of the mobility ratio between the oil and aqueous phases. Surfactant solutions reduce permeability to water and improved rock wettability, reduce the adsorption of the polymer, and thereby improve the viscoelastic characteristics of the polymer solutions. These processes significantly improves processes of oil-displacing. To achieve high process efficiency in view of the factors mentioned positive polymer composition should be injected into the formation after treatment of the formation by the surfactant solution. The content of the surfactant in solution improves the rheological properties of polymer solutions in the formation waters.

During ASP flooding when surfactant are added and mixed with oil and formation water formation of emulsion can occur. The key mechanisms that occur in the formation are alkali emulsification and generation of soap leading to reaction with the crude oil. Surfactant allows to make emulsion stable reducing IFT, increasing interface strength and generating charge at interface. Polymer is used for increasing water viscosity. Thus, higher viscosity reduce the diffusion of droplets leading to less coalescence, therefore emulsion stability is improved. As the number of dispersed droplets increases, viscosity of emulsion is increased and stability is improved [6].

Displacement mechanisms in ASP technology can be summarized as follows:

- Increased capillary number effect to reduce residual oil saturation because of low IFT
- Improved macroscopic sweep efficiency because of the viscous polymer drive
- Improved microscopic sweep efficiency and displacement efficiency as a result of polymer viscoelastic property
- Emulsification, entrainment, and entrapment of oil droplets because of surfactant
- effects
- Improved sweep efficiency

As for polymer and surfactant placement experimental data from Chen and Pu (2006) showed that injection of polymer slug before surfactant slug led to a higher recovery factor than the injection of mixing slug of surfactant and polymer. Besides, based on experimental results, Yang and Me (2006) noticed that when polymer was injected separately from the alkaline and surfactant slug, the incremental oil recovery was higher than when polymer was injected with alkali and surfactant placed in the same slug. Also they reported that it was better to place polymer in the preflush slug than in the post-flush slug, and this conclusion is supported by the experiments reported by Li (2007). On the other hand, some experiments show almost the same recovery factors for separate injection of polymer and surfactant and joint injection. Thus, for determination of the most optimum variant of polymer and surfactant injection it is recommended to simulate different cases for certain field with its geological conditions.

As for time to shift waterflood to SP flooding it was studied that the later SP flooding is started the higher total injection PV is required in order to achieve the same recovery factor as at initial stages. Thus, it is better to start SP flooding earlier to accelerate production and reduce water injection. At the late stage more water is required to displace residual oil since this oil is trapped or bypassed by displacing fluid at lower initial oil saturation. Therefore, SP flooding should start at higher oil saturation to achieve higher oil recovery factor.

Despite this fact, a SP flood could never be started from the beginning of the field development for several reasons:

- chemical flood requires a long preparation time, including laboratory investigations
- in order to run a chemical flood project more technical skills and competence are needed
- more time is needed to get the project approved
- an early waterflood history is required for the reservoir characterization

This is the key justification for the late start of a chemical flood [1].

6. Заключение

Полимерное заводнение с применением поверхностно-активного вещества и полимера является популярным и широко-изучаемым методом повышения нефтеотдачи пласта во всем мире. На сегодняшний день данный метод применяется во многих проектах за рубежом, которые показали положительные результаты и значительный прирост добычи нефти. В России начинают применять данную технологию на Западно-Салымском месторождении, где планируют прирост коэффициента извлечения нефти до 50-60%. Однако, полимерное заводнение с добавлением ПАВ и щелочи применяется в основном в терригенных коллекторах, так как карбонатные коллектора усложняют этот процесс из-за наличия трещин и каверн в породе. Эксперименты в таких карбонатных коллекторах проводятся в лабораториях на керне месторождения, где планируется применять данную технологию.

Керн Пашкинского месторождения был исследован в лабораторных условиях для выявления свойств породы и подбора определенного полимерного раствора, щелочи и ПАВ. Согласно лабораторным исследованиям, было доказано, что щелочь является малоэффективной в условиях карбонатных коллекторов. Также в результате лабораторного анализа были выбраны наиболее эффективные растворы полимера и ПАВ с определенной концентрацией.

В данной работе были выбраны объекты под закачку реагентов на основании геолого-физических критериев. Также в работе использовалась гидродинамическая модель, где были рассмотрены разные режимы закачки полимерного раствора для каждой нагнетательной скважины, после чего наиболее эффективные варианты были объединены в один общий, чтобы проанализировать эффект. Коэффициент извлечения составил 27,72% по сравнению с базовым случаем 27,0%. Прирост добычи нефти составил 28 тыс. тонн нефти. После этого были рассмотрены разные режимы закачки для ПАВ-полимерного заводнения также для каждой скважины и объединены в общий вариант. Коэффициент извлечения нефти увеличился незначительно, составив 27,83%. Прирост добычи составил 32 тыс.тонн нефти. Далее для обоих вариантов был посчитан экономический эффект, где прибыль для полимерного заводнения составила 60 млн.руб, прибыль для ПАВ-полимерного заводнения – 42 млн.руб. Таким образом, в условиях Пашкинского месторождения при наличии карбонатных пластов и многопластовой залежи наиболее эффективным вариантом является полимерное заводнение. Также в работе было рассмотрено влияние анизотропии на полимерное заводнение и анализ неопределенностей.

На сегодняшний день, ученые продолжают исследования в направлении поиска путей для обеспечения максимальной продолжительности эффекта полимерного заводнения. Основная задача состоит в том, чтобы защитить полимеры от преждевременного разрушения и обеспечить улучшение их положения во внутреннее пространство резервуара на расстояние, достаточное для перераспределения нагнетаемой воды. Опыт показывает, что композиции должны быть выбраны для конкретных геологических условий. Кроме того, требуется тщательное изучение условий и критериев использования этих технологий, особенно в карбонатных коллекторах, которые играют важную роль кавернозных и разрушения.

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