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Satbayev University

ХАБАРЛАРЫ

ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК
РЕСПУБЛИКИ КАЗАХСТАН
Satbayev University

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Қазақстан Республикасы Ұлттық ғылым академиясы «ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы» ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Webof Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді геология және техникалық ғылымдар бойынша контентке адалдығымызды білдіреді.

НАН РК сообщает, что научный журнал «Известия НАН РК. Серия геологии и технических наук» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Известия НАН РК. Серия геологии и технических наук в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному контенту по геологии и техническим наукам для нашего сообщества.

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EXPERIMENTAL STUDIES OF CHEMICAL AND TECHNOLOGICAL CHARACTERISTICS OF CROSS-LINKED POLYMER SYSTEMS APPLIED IN FLOW-DIVERSION TECHNOLOGIES

Abstract: currently, most of the oilfields in Kazakhstan are entering the stage of development (brown fields), which is characterized by a decrease in oil production, an increase in the volume of associated water. Often, commercial wells are completely watered, while a significant part of the oil-saturated reservoir remains undeveloped. In this case, a large amount of material resources is spent on raising water to the surface. The low efficiency of oil production at the stage of a brown field is largely due to the geological and physical heterogeneity of the developed reservoirs. There fore, one of the main issues in the development of fields with geological heterogeneity is the active utilization of poorly drained or non-drained reservoir sections.

In recent years, the number of successfully applied physicochemical methods of enhanced oil recovery includes polymer flooding and its modifications (flow diversion technologies - FDT), aimed at the conformance control (CC) of injection wells. This leads to a limitation of water filtration through highly permeable interlayers, an increase in the coverage of a heterogeneous reservoir as a whole, thereby ensuring an increase in the ultimate oil recovery factor (ORF) due to the extraction of oil from undeveloped zones.

Experience in the development of oilfields has shown that the use of FDT depends on the geological and physical conditions of the field. There fore, one of the conditions for the effective use of FDT is the correct selection of the geological and physical conditions of the object for the applied technology. In this case, the main role will belong to models that allow for predictive assessment of the effectiveness of technological solutions in the considered geological and physical conditions.

Key words: well, conformance control, oilfield, ORF, skin factor, bottomhole formation zone.

Materials and research methods. When solving the set tasks, the methods of experimental research, statistical methods, and methods known from the theory of fuzzy sets were used when constructing models and assessing the effectiveness of their application when predicting the oil recovery factor in various geological and physical conditions.

Scientific novelty. As known, the effectiveness of the use of FDT based on polymer solutions depends on their good selective filterability in zones with high water saturation, which makes it possible to create watertight barriers in the desired direction and to a sufficient depth. The controllability of the CC process in terms of the degree and duration of the blockage of the watertight barrier is determined by the rheological and filtration characteristics of the polymer solutions. In this regard, the determination of the best parameters of the FDT is an urgent task, the solution of which will improve the efficiency of the selection of technological options in relation to each specific field with different geological and physical conditions.

Linear and multiplicative models are constructed to forecast estimation of the oil recovery factor, the area of their application is substantiated from the point of view of individual conditions due to the ambiguity of the calculation results.

The experience of developing oilfields has shown that due to the multi-layer structure, zonal and layer-by-layer heterogeneity in permeability and oil saturation, the presence of high viscosity oil in the productive horizons, the initial pressure gradient as a result of abnormal oil properties and clay content in them, high rates of fluid withdrawal, disturbances casing of the well and a number of other technical and technological indicators, there is

anticipatory flooding either by formation water or by water injected to maintain reservoir pressure, high-permeability and water-saturated areas of the production facility and partial or complete withdrawal from the development of medium and low permeable layers [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, etc.]. As noted in this paper [15], the problem of water inflow into wells is relevant not only for wells in operation but also for those that have just been drilled. In recent years, the volume of commissioned wells that require repairs due to the breakthrough of the bottom waters and the influx of water from water-saturated formations close to the productive zone has sharply increased. This leads to a decrease in the coverage of the reservoir by the effort, the production of huge volumes of water, which, moving through the already washed zones, does not perform useful work to displace oil. With a total world oil production of 11 million tons per day, about 45-60 million tons of water per day are produced along with it, which is about 5-6 tons of water for each ton of oil. In the USA, where many fields are depleted, the ratio of water to oil is 9: 1 [16].

As a result of the above negative phenomena, many oilfields in Kazakhstan also have a high water cut and low current oil recovery. For example, at the facilities of the Zaburunye field, the water cut is 70.1-91.5%, and the current oil recovery is 14.2-37.2%, at the facilities of the Zhetybai field, respectively, 60.1-97.9% and 4.2-45, 3, at the facilities of the Western Prorva field 27.4 - 79.8% and 2.6-36.7%, at the facilities of the Karazhanbas field 74.71 - 92.5% and 3.9-24.6%, at the facilities of the Kalamkas field 82.6 - 94.8% and 10.2-37.8%, etc. In addition to the above, the high water cut of the product leads to unproductive costs associated with the extraction and transportation of produced water and its further utilization. Waterflooding is by far the most advanced form for the efficient development of oilfields. The introduction of waterflooding made it possible to increase the oil recovery factor at oilfields with different geological and physical conditions by 2-2.5 times, compared with those achieved at similar ones developed at natural depletion modes.At the same time, the most important task facing oil-producing companies is to achieve maximum oil recovery.

The oil recovery factor is one of the main technological indicators of the efficiency of oilfield development. Its value is influenced by a large number of factors that depend both on objective ones, i.e. factors characterizing natural conditions, as well as subjective, i.e. associated with the "human factor". In the context of the deterioration of the structure of oil reserves in Kazakhstan, the scientific substantiation and implementation of methodological approaches, methods, and models and the effective stimulation of the reservoir associated with these technologies are becoming urgent. In this case, when making decisions on methods, technologies, and monitoring of oilfield development, the reliability of the oil recovery factor assessment becomes the main determining factor. In parallel, it becomes necessary to assess and analyze the influence of geological and physical factors on the value of the oil recovery factor in the considered oilfield, which can be ensured by building appropriate models. A number of research pieces is addressing this problem. In particular, it should be noted the studies, the results of which are given in the research papers [15,16]. These papers provide statistical models built to forecast oil recovery rates for various oilfields. For all the usefulness of these models, it should be noted that due to the specific features of each oilfield, they are not universally applicable. Therefore, in each case under consideration, it is necessary, on the basis of analysis, to consider the possibility of building similar models based on the data of a particular oilfield.

As shown in a number of papers, including in [2, 4, 6, 7, 11, 14], in the current conditions, one of the solutions in the development of measures to improve the efficiency of the oilfield development process is the use of methods and technologies based on limiting unproductive filtration of water in horizons. Thus, the problem is reduced to the improvement and creation of a set of methods and means for limiting the movement of water in the washed zones of the productive formation and bottomhole zones of wells, which will increase the efficiency of oil extraction from deposits and the performance of production wells.

Studies [6, 12] devoted to the movement of polymer solutions in a porous medium and water injected after them, have shown that its character is determined by the following properties that are not inherent in many other chemical agents. On one hand, the viscosity of polymer solutions, depending on the shear rate, can decrease or increase [6, 12, 15]. On the other hand, polymer solutions in contact with a porous medium reduce its permeability. Moreover, the effect of reducing the permeability of the porous medium after its contact with the polymer is retained even after tens and hundreds of pore volumes of water are pumped through it [2, 11]. To describe the effect of decreasing permeability after contact of a porous medium with polymers, [16] it was introduced the concept of a residual resistance factor (R_{res}), which is defined as a value representing the ratio of the permeability of

a porous medium to water before and after it is treated with a polymer solution:

$$R_{res} = \frac{q_w}{q_p} \quad (1)$$

where q_w, q_p - respectively, is the water permeability of the porous medium before and after the treatment of the porous medium with a polymer solution.

In [6, 20], a large number of studies were carried out to understand various aspects of the formation mechanism of the residual resistance factor during the treatment of a porous medium with polymers.

As a result of these studies, it was found that the decrease in rock permeability occurs primarily due to the adsorption of the polymer on a solid surface [5] and the formation of a monomolecular polymer layer with high mechanical properties on the pore surface [12].

In addition to adsorption, the formation mechanism R_{res} is influenced by the non-Newtonian properties of polymer solutions [6, 12, 13]. Thus, in [6, 7], it was found that, in contrast to an untreated porous medium, where the nature of the fluid flow is Newtonian, after its treatment with a polymer solution with an increase in the filtration rate, the fluid flow has a dilatant character, and in [13] - pseudoplastic.

It is known that one of the factors affecting the efficiency of oilfield development is the state of the bottomhole zones of wells [12]. This part of the formation is most susceptible to various physicochemical and thermodynamic changes.

As noted in [12, 18], the main reasons for the decrease in the permeability of the bottomhole formation zone (BHZ) of injection and production wells are: partial or complete clogging of the pore space with a solid phase of a clay solution during the opening of the formation by drilling and perforation, as well as a solid phase of drilling fluid during repair and insolation works in the well; clogging of the bottomhole formation zone with mechanical impurities and corrosion products introduced into the formation by injected water; increased residual oil saturation of individual interlayers adjacent to the bottomhole zones of injection wells; clogging of the bottomhole formation zone with oxidized oil when injecting wastewater into strata; swelling of reservoir clays when interacting with fresh water and solutions of some chemicals, leading to a decrease in the absolute permeability of the formation, especially in low-permeability layers; a decrease in the permeability of the reservoir rock by 15-60% (can occur when changing from saline formation water to freshwater).

As a result of the influence of these factors, the properties of the bottomhole formation zone (skin factor [19, 20] is the numerical value of the dimensionless quantity S with the “+” or “-” sign, characterizing the deterioration or improvement of permeability in the bottomhole zone and the degree of its improvement or deterioration) will differ from properties of the entire reservoir. In this regard, one of the goals of bottomhole formation treatments is to increase or decrease the permeability in the bottomhole zone in order to maintain or increase the flow of oil from oil-saturated layers.

To date, as a result of research [4, 5, 6, 12, 13, 15, 16], a large amount of information has been accumulated on laboratory studies and field experience in the use of polymers to limit water inflows in production wells and conformance control in injection wells.

Based on laboratory studies and field experience, [6, 15] it is proposed two mutually complementary mechanisms that explain the effect of increasing oil production or slowing down the rate of decline in oil production during polymer treatments, which are essentially similar and differ only in the scale of consideration of the selective horizon plugging process. According to the first mechanism, in the beginning, the polymer penetrates during injection into the most permeable flooded interlayers and reduces their water permeability, which leads to a redistribution of filtration flows of water and oil over the reservoir thickness. Well productivity index is decreasing. A decrease in water content in a well's production while maintaining production, and in some cases, reducing it, leads to a decrease in bottomhole pressure, an increase in drawdown. Oil-saturated (low-permeability) interlayers begin to work with a high flow rate since the increase in the drawdown does not compensate for the deterioration of the permeability of water-saturated interlayers.

The review has shown that today polymer flooding is one of the most important methods of enhanced oil recovery, which improves the ratio of water and oil mobility. Even a small amount of polymer solutions leads to an increase in the viscosity of water and when injected into the reservoir, its permeability decreases due to blocking of high-permeability zones, and thus a more uniform displacement of the front is created, leading to an increase in the efficiency of displacement in terms of area and reservoir thickness, which in turn further contributes to the reduction of water breakthrough in production wells [14]. Polyacrylamides and polysaccharides, which have long chains with high molecular weight side branches, increase the mobility of the oil in relation

to the mobility of water due to the increased shear stress of the composition.

The kinetics of gelation was studied using a Relaxometer. This device makes it possible to evaluate the relaxation time in polymer systems under the action of a force field arising from the intense longitudinal stretching of the composition sample. The principle of operation of the device is based on the formation of a filament from a sample and subsequent assessment of the filament lifetime as a characteristic of relaxation processes. Studies on the time of gelation were carried out at a temperature of 30°C in the range of polymer concentrations from 0.3 to 0.5%.

The concentration of chromium acetate was taken in the range of 0.03-0.05%. The results of experiments to determine the gelation time in the compositions "polymer-crosslinker" are presented in Table1

Table 1 - Gelation time and flow rates in polymer compositions (T = 30°C).

Composition:	**Flow rate**	**Gelation time, hour**
Cp = 0.3% Cca = 0.03%	0.656	34.5
Cp = 0.4% Cca = 0.04%	0.704	27.8
Cp = 0.5% Cca = 0.05%	0.788	23.2

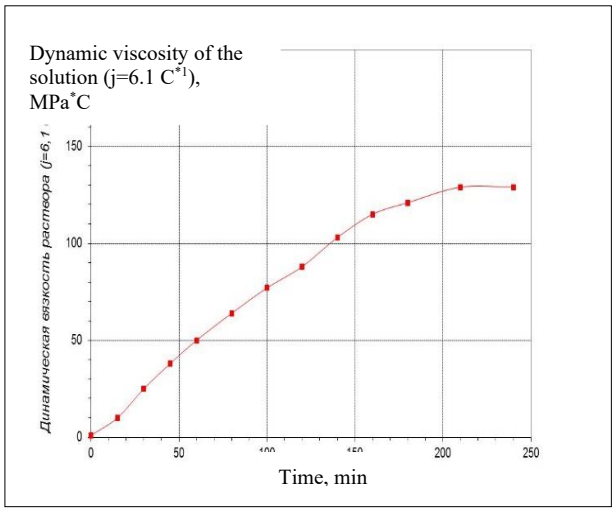


Figure 1 - Kinetics of dissolution of the FP-307 polymer at t =25°C.

Results and discussion. As can be seen from the data presented, with an increase in the polymer concentration in the polymer-crosslinker compositions, the gelation time decreases.

Thus, the experiments carried out showed that the FP-307 polymer is well compatible with the mineralized water of the Karazhanbas deposit. The composition based on the investigated polymer FP-307 with chromium acetate as a crosslinker, depending on the type of volumetric or shear deformation, can exhibit viscous or elastic properties. Therefore, for the successful use of the FP-307-chromium acetate polymer composition in the field conditions, the correct choice of the object and parameters of the process being carried out is necessary.

The composition was injected into injection well 474 in a volume of 508 m^3 (FP-307 polymer, chromium acetate (CA) and wood flour) also carried out in 4 cycles:

- in the first cycle on September 26-27, 2018, 108m3of the composition was injected into the formation: 0.5% polymer slurry (FP-307) with 0.05% chromium acetate crosslinker;

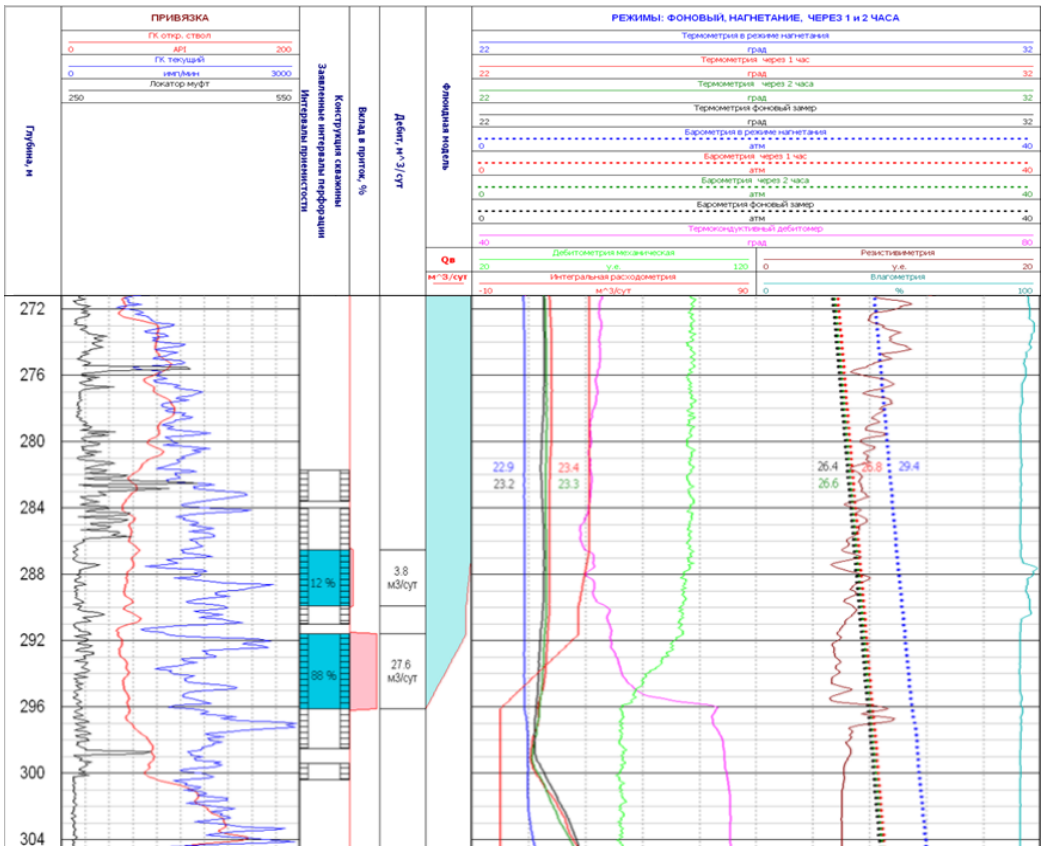
- in the second cycle on September 27-29, 2018, 200m3of the composition was injected into the formation: 0.4% wood flour, 0.5% polymer pulp (FP-307) with 0.05% chromium acetate crosslinker; the composition was squeezed with water in a volume of 4-8 m^3 with its exposure for 1 day to carry out the gelation process;

- in the third cycle, September 29-30, 2018, 150m3of the composition was injected into the formation: 0.4% wood flour, 0.5% polymer pulp (FP-307) with 0.05% chromium acetate crosslinker; at a pressure of 3.8 MPa, the composition was again squeezed with water in a volume of 4-8 $m^3$and held for 1 day to carry out the gelation process;

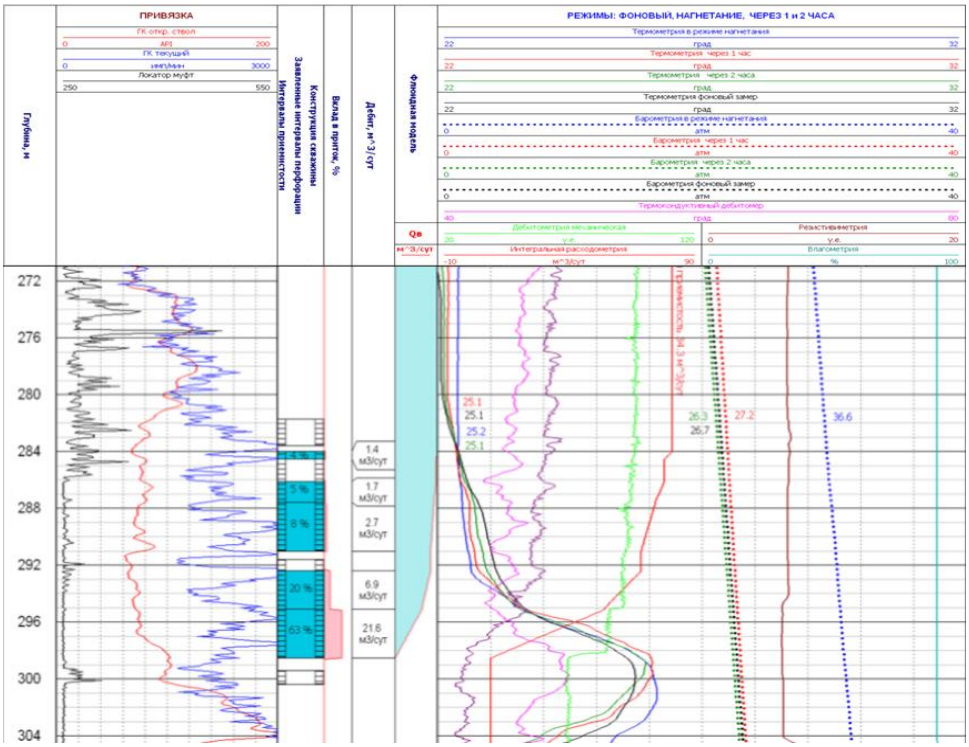
As can be seen from Figures 2 and Table 2, before the injection of the composition, the average sweep efficiency was for wells. 3696 47% with injectivity of 31.4 m^3/day, after injection the sweep factor increased to 68.5% with injectivity of 34.3 m^3/day.

Table 2 - Geophysical parameters of the well 3696 before and after the CC.

Before CC							
perforation intervals, meters (m)		injectivity intervals, meters (m)		sweep efficiency, %	effect on injectivity		fluid composition
top	bottom	top	bottom		m3/day	%	
281.7	283.6						
284.0	291.0	286.5	289.9	48.6	3.8	12.0	water
291.6	298.5	291.6	296.1	65.2	27.6	88.0	water
299.4	300.4						
Total				47.0	31.4		
After CC							
perforation intervals, meters (m)		injectivity intervals, meters (m)		sweep efficiency, %	effect on injectivity		fluid composition
top	bottom	top	bottom		m3/day	%	
281.7	283.6						
284.0	291.0	284.0	284.5	77.1	1.4	4.0	water
		286.1	287.6		1.7	5.0	water
		287.6	291.0		2.7	8.0	water
291.6	298.5	292.4	295.1	88.4	6.9	20.0	water
		295.1	298.5		21.6	63.0	water
299.4	300.4						
Total				68.5	34.3		



a)



b)

Figure 2. Formation injectivity GIS before (a) and after (b) the well CC. 3696

Thus, the results of pilot testing of flow diverting technology at a field in Western Kazakhstan showed that a composition based on crosslinked polymer compositions (FP-307 polymer (PAA) with chromium acetate as a crosslinker) and wood flour (WF) creates an opportunity for effective regulation of the direction of filtration flows and involvement in the development of zones with reduced permeability. This leads to a decrease in the water cut and an increase in the oil production rate of the surrounding production wells, hydrodynamically connected with the injection wells.

Conclusions. An analysis of the results of the practical application of a polymer-based agent in the considered areas of fields in Western Kazakhstan showed high technological efficiency while providing an opportunity for effective regulation of the direction of filtration flows and involvement of zones with reduced permeability into development. A decrease (or stabilization) of water cut was observed in almost all wells. Above are the performance indicators (oil flow rate, water cut) for four wells before and after the measures taken. The given data proof a sufficiently high efficiency of the technology. The results of the analysis indicate the possibility of obtaining a high technological effect from the use of solutions of the polymer FP-307 (PAA) with chromium acetate as a crosslinker in the conditions of the oilfileds of Western Kazakhstan.

Based on the results of pilot testing (PT) of flow diverting technology at the oilfields of Western Kazakhstan, the following conclusions can be drawn:

- field tests of the technology based on increasing the sweep of the reservoir by waterflooding using the conformance control of the injection well based on the creation of a flow diverting barrier in the bottomhole zone made it possible to substantiate its effectiveness in the geological conditions under consideration;

- an improved methodological approach to the use of flow diverting technology to improve the efficiency of oilfield development based on a crosslinked polymer system (FP-307 polymer (PAA) with chromium acetate as a crosslinker) and wood-flour was proposed, which made it possible to achieve a decrease in water cut and an increase in production, which in turn will allow minimizing the economic and technological risks of the oil company.

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АҒЫНДЫ ӨЗГЕРТУ ТЕХНОЛОГИЯСЫНДАҒЫ ПОЛИМЕРЛІК ЖҮЙЕЛЕРІНІҢ ХИМИЯЛЫҚ ТЕХНОЛОГИЯЛЫҚ СИПАТТАРЫНЫҢ ЭКСПЕРИМЕНТТІК ЗЕРТТЕУЛЕРІ

Аннотация: қазіргі кезде Қазақстандағы кен орындарының көпшілігі игерудің соңғы кезеңіне аяқ басты, бұл мұнай өндірудің төмендеуімен, ілеспе су көлемінің ұлғаюымен сипатталады. Көбіне өндіруші ұңғымалар толығымен суланады, ал мұнаймен қанықкан қабаттың едәуір бөлігі игерілмей қалады. Бұл жағдайда үлкен көлемдегі материалдық ресурстар жер бетіне қарай судың көтерілуіне жұмсалады. Кейінгі кезеңдегі мұнай өндірудің төмен тиімділігі көбінесе игерілген су қабаттарының геологиялық және физикалық гетерогенділігіне байланысты. Сондықтан геологиялық біртектілігі жоқ кен орындарын игерудің негізгі мәселелерінің бірі – әлсіз дренаждалған немесе жалпы құрғап кетпейтін су қабатының учаскелерін белсенді жұмысқа тарту болып табылады.

Соңғы жылдары мұнайдың өндіру коэффицентін қалпына келтірудің табысты қолданылған физико-химиялық әдістерінің қатарына айдау ұңғымаларының қабат профильдерін түзету (ҚПТ) қабат профилін түзетуге бағытталған полимерлі суландыру және оның модификациялары (ағынды бұру технологиялары – АБТ) кіреді. Бұл су өткізгіштігі жоғары қабаттар арқылы суды сүзудің шектелуіне, тұтасымен гетерогенді қабаттың жабылуының ұлғаюына әкеледі, осылайша игерілу аймақтарынан мұнай алу нәтижесінде мұнайдың соңғы қалпына келтіру коэффициентінің (ҚКК) жоғарылауын қамтамасыз етеді. Мұнай кен орындарын игеру тәжірибесі көрсеткендей, АБТ пайдалану кен орнының геологиялық және физикалық жағдайларына байланысты. Сондықтан АБТ-ны тиімді пайдалану шарттарының бірі – қолданылатын технологияға арналған объектінің геологиялық және физикалық жағдайларын дұрыс таңдау. Бұл жағдайда басты рөл қарастырылатын геологиялық және физикалық жағдайлардағы технологиялық шешімдердің тиімділігін болжамды бағалауға мүмкіндік беретін модельдерге тиесілі болады. Өздеріңіз білетіндей, полимерлі ерітінділерге негізделген АБТ-ны қолданудың тиімділігі олардың судың қанықтылығы жоғары аймақтардағы жақсы селективті сүзгіштікке байланысты, бұл суды оқшаулағыш экрандарды қажетті бағытта және жеткілікті тереңдікте жасауға мүмкіндік береді. Су тоскауылының бітелу дәрежесі мен ұзақтығы бойынша ҚПТ процесінің бақылануы полимерлі ерітінділердің реологиялық және сүзу сипаттамаларымен анықталады. Осыған байланысты АБТ-ның ең жақсы параметрлерін анықтау кезек күттірмейтін міндет болып табылады, оны шешу әр түрлі геологиялық және физикалық жағдайлары бар әрбір нақты кен орнына қатысты технологиялық нұсқаларды таңдау тиімділігін арттырады.

Түйін сөздер: ұңғы, қабат профилін түзету, кен орны, мұнайды өндіру коэффициенті, скин фактор, ұңғыманың түп аймағы.

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ЭКСПЕРИМЕНТАЛЬНЫЕ ИССЛЕДОВАНИЯ ХИМИКО-ТЕХНОЛОГИЧЕСКИХХАРАКТЕРИСТИКСШИТЫХ ПОЛИМЕРНЫХ СИСТЕМ, ПРИМЕНЯЕМЫХ В ПОТОКООТКЛОНЯЮЩИХ ТЕХНОЛОГИЯХ

Аннотация: в настоящее время большинство месторождений Казахстана вступают в позднюю стадию разработки, которая характеризуется снижением добычи нефти, повышением объёма попутно добываемой воды. Часто добывающие скважины полностью обводняются, в то время как еще значительная часть нефтенасыщенного пласта остается невыработанной. При этом затрачивается большое количество материальных средств на подъем воды на поверхность. Невысокая эффективность добычи нефти на поздней стадии во многом связана с геолого-физической неоднородностью разрабатываемых пластов. Поэтому одной из главных проблем разработки месторождений с

геологической неоднородностью является вовлечение в активную работу слабодренируемых или вообще недренируемых участков пласта.

В последние годы в число успешно применяемых физико-химических методов повышения нефтеотдачи входит полимерное заводнение и его модификации (потокоотклоняющие технологии - ПОТ), направленные на выравнивание профилей приемистости (ВПП) нагнетательных скважин. Это приводит к ограничению фильтрации воды по высокопроницаемым пропласткам, увеличению охвата неоднородного пласта в целом, обеспечивая тем самым повышение конечного коэффициента извлечения нефти (КИН) за счет извлечения нефти из невыработанных зон.

Опыт разработки нефтяных месторождений показал, что применение ПОТ зависит от геолого-физических условий месторождения. Поэтому одним из условий эффективного применения ПОТ является правильный подбор геолого-физических условий объекта под применяемую технологию. При этом основная роль будет принадлежать моделям, позволяющим давать прогнозную оценку эффективности технологических решений в рассматриваемых геолого-физических условиях.

Как известно, эффективность применения ПОТ на основе полимерных растворов зависит от хорошей селективной фильтруемости их в зоны с высокой водонасыщенностью, позволяющей создавать водоизолирующие экраны в желаемом направлении и на достаточную глубину. Регулируемость процесса ВПП по степени и продолжительности закупорки водоизолирующего экрана определяется реологическими и фильтрационными характеристиками полимерных растворов. В связи с этим определение наилучших параметров ПОТ является актуальной задачей, решение которой позволит добиться повышения эффективности выбора технологических вариантов применительно к каждому конкретному месторождению с различными геолого-физическими условиями.

Ключевые слова: скважина, выравнивание профиля пласта, месторождение, КИН, скин-фактор, ПЗП.

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