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NOVEL WATER SHUT OFF METHOD BASED ON TEMPORARY PLUGGING AGENT AND GEL COMPOSITION SHUT-OFF

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A B S T R A C T

This article presents the laboratory development of a novel rigless, self-selective water shut-off technique. The technique involves the design and pumping of three different fluids through fractured core plugs in a specific sequence. The first fluid serves to temporarily block porous medium while moving freely through fractures. The second fluid is a cross-linking polymer gelant, which is injected immediately after the first fluid at a pressure below the fracture pressure of the formation to block fractures. An enzyme-based chemical breaker solution, serving as the third fluid, is evaluated for removing the filter-forming materials. The treatment and flow studies are conducted using a high-pressure, high-temperature core flow setup. In conclusion, the developed water control technology presented in this study offers a low-cost solution for fractured and high-anomaly wells. The technology is particularly effective when there is a significant permeability contrast between the oil-bearing matrix and water-conductive fractures. The results demonstrate a successful blockage of fracture, with minimal contamination of porous medium. The study also highlights important factors to consider for the field application of this technology. It is recommended to conduct customized laboratory investigations under simulated reservoir conditions prior to implementing the technology in the field. This will help optimize the treatment design and ensure its effectiveness in real-world applications.

Keywords: water shut-off; temporary blocking agent; gel composition; coreflood; permeability contrast.

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Introduction

High water cut production in mature oil fields is a persistent and challenging issue, particularly exacerbated by extended reach drilling and multilateral wells [1-3]. These wells often intersect multiple conductive fractures, faults, and highly permeable streaks, leading to increased water production due to the mobility advantage. Unless equipped with intelligent flow control or individual well segment shut-off capabilities, managing excessive water production relies on chemical (polymer gel) or mechanical methods [4-13]. However, the successful application of polymer gels in water control has mostly been limited to vertical and short horizontal wells with well-characterized reservoir characteristics [14-16].

Reservoirs with long horizontal sections pose additional challenges, including identifying water-conductive zones, accurately placing the appropriate volume and type of gelant, and protecting oil-bearing zones from potential damage caused by invading polymer gels. Reservoirs containing numerous conductive fractures or high-permeable thief zones present technical and economic difficulties in identifying, isolating, and safeguarding oil-bearing zones from gelant invasion. Various approaches have been proposed in the literature to address these challenges, but most have proven ineffective during field trials [17-20].

Contrary to common belief, detailed analysis has shown that water-based polymer gelants do not preferentially enter water-flooded zones over highly oil-saturated zones, except in reservoirs with high oil/water viscosity ratios. Bullheading of cross-linked polymer gel has generally been unsuccessful in fractured reservoirs, as it reduces both water and oil production rates. Some polymer gels, known as Relative Permeability Modifiers (RPM), have been considered advantageous for blind and bullhead treatments as they reduce water permeability more than oil permeability. However, the application of RPM is limited due to increased irreducible water saturation caused by polymer adsorption, leading to a reduction in oil relative permeability [21-23].

This article presents the laboratory development of a novel rigless, self-selective water shut-off technique. The technique involves the design and pumping of three different fluids through fractured core plugs in a specific sequence. The first fluid consists of suspended micro-fibrous particles in a viscous solution. It is pumped to create an impermeable filter cake on the low permeable oil-bearing zones while allowing fluid passage through the fractures. The second fluid is a cross-linking polymer gelant, which is injected immediately after the first fluid at a pressure below the fracture pressure of the formation. The gelant selectively penetrates and

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seals only the fractures because the low permeable matrix zones are already protected by the impermeable filter cake formed by the first fluid. An enzyme-based chemical breaker solution, serving as the third fluid, is evaluated for removing the filter-forming materials. The treatment and flow studies are conducted using a high-pressure, high-temperature core flow setup.

Materials and methods

Porous media

Sandstone core plugs with permeability ranging from 100 to 700 mD were subjected to cleaning, and their absolute brine permeability were measured. To create fractures in the core plugs, they were cut into two halves using a diamond core cutter. To achieve low, medium, and high aperture fractures, sand grains of varying sizes were placed and combined using a heat shrink technique.

Table 1 provides the petro-physical properties of the whole core sand fractured cores, including fracture aperture data. Fracture width was determined using an optical stereo microscope (OSM).

Temporary plugging agent for matrix protection (Fluid1)

The purpose of fluid 1 is to create an impermeable barrier on the surface of the matrix while keeping the fractures open for the invasion of the polymer gelant. To achieve this, certain properties are desired for fluid 1:

- The suspended fibers should have a small enough size to flow freely through the high permeability fractures.
- The fibers should be large enough to avoid entering the matrix area but capable of forming an impermeable filter cake.
- The particle size distribution (PSD) of the fibers should be narrow.
- The fibers should be easily degradable using a suitable chemical breaker to restore the original permeability of the oil-bearing matrix.

To fulfill these requirements, micronized cellulose fibers mixed with an aqueous solution of xanthan polymer (XP) with an optimum viscosity. The final composition of fluid 1 was as follows: 0.5% xanthan polymer and 3% cellulose fiber in a 5% NaCl solution. The final solution was screened through micropore filter (0.22 mm) to achieve narrow Particle Size Distribution. The final PSD of the solution was estimated using Horiba LB-550 Particle Size Analyzer.

Gelant solution (Fluid 2)

The gelant solution was prepared according to [24]. Gelation time of composition was 11 hours.

Breaking solution (Fluid 3)

The cleaning solution used to dissolve the filter cake forming materials, which primarily consisted of cellulose fiber and xanthan polymer, comprised a mixture of xanthanase (5%), a combination of *a* and *b* amylase (6%), and 5% $CaCl_2$ brine. Since the composition mainly consists of bio-enzymes, there is no risk of creating wormholes or fractures that could pose a threat to the well.

Brine

In order to prevent clay swelling and any alterations in the properties of the core, a 5% NaCl solution in distilled water was utilized as the aqueous phase for both the flow studies and the preparation of the treatment fluids. The solution was filtered through a membrane filter to ensure its purity and remove any potential contaminants.

Core flow description

In the core flow studies, the evaluation criteria were based on the permeability brine at various stages of treatment (fig. 1). The below steps were followed during the test:

1. Core samples were loaded into a core holder under 300 bar confining pressure (simulating overburden pressure) and 60 bar back pressure (to eliminate free gas in the system) at 75 °C. All treatments were conducted in the forward direction, while permeability measurements were conducted in the reverse direction, simulating flow direction from the reservoir to the wellbore.
2. Permeability measurements were performed at a steady flow rate of 1 ml/min until stabilized differential pressures were achieved. These permeabilities represented the matrix permeability or initial permeability of the unfractured formation.
3. The core plugs were then dislodged from the core holder, cleaned, dried, and a fracture was created alongside the length of the core using a diamond cutter. The core plugs were joined again with a plastic heat shrink.
4. The core plugs were examined under a microscope to measure the fracture aperture. Then were placed into core holder again
5. Fluid 1 was injected into the porous medium in order to plug porous medium (uncracked zones of core). The permeability could not be measured at this stage, as the permeability value was beyond the measurable interval due to presence of crack.
6. Fluid 2, the gel at its initial, low viscous condition, was then injected into the core. A total of 2 pore volumes of gel were injected for each core. The system was shut in for 12 hours to complete the gel formation.
7. The permeability of cores was measured to ensure plugging efficiency of both the first and second fluid.
8. Fluid 3 (clean-up fluid) was injected into the core. 4-hour soaking period was provided.
9. After completing the cleaning steps, return permeability was measured from the reverse direction at a steady flow rate of 1 ml/min.

Table 1

Properties of core samples

Core No	Length, cm	Diameter, cm	Porosity, %	Initial permeability, mD	Fracture width, mm
Core 1	9.43	5.04	18.7	128	1.2-1.6
Core 2	9.38	5.06	20.3	337	1.3-1.6
Core 3	9.41	5.05	21.1	674	1.2-1.5

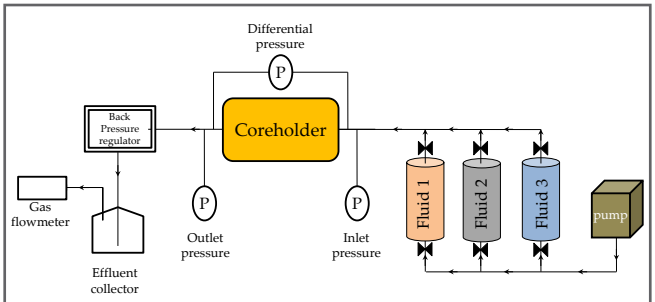

Fig. 1. Schematic represegntation of coreflood apparatus

Results and discussion

Particle Size Distribution of temporary plugging agent

To protect the matrix area from invasion by the blocking gel, temporary plugging agent was injected prior to gelant solution. The criteria of temporary plugging agent are described in previous section. Approximately 90% of the particles of prepared solution fell within the range of 120-190 μm sizes.

It was anticipated that the suspended fibrous particles would deposit on the matrix zones and create a filter cake. However, due to their smaller size and flexibility, these particles could easily flow through the fractures, allowing the flow path through the fractures to remain open. Even if the fracture width was slightly smaller than the size of the suspended fibers, their thread-like structure and flexibility enabled them to penetrate and remain in a fluid state inside the fractures.

Results of coreflood experiments

To assess the treatment results quantitatively, permeability values at following stages were plotted in figure 2:

- permeability of initial/unfractured core samples;
- permeability of core samples with fracture – this estimation was beyond measurable interval of apparatus. It is only displayed for comparison and accepted as more that 10 D;
- permeability of core after injection of second fluid/ gel composition – this measurement shows effect of both temporary blocking agent and gel composition;
- permeability of core after injection of 3rd fluid – this is final condition of core samples.

This observation displays the effectiveness of breaking solution.

The results show that the final permeability, is slightly higher than initial permeability, especially for cores with low permeability. This can be attributed to the flushing out of some invaded polymers during the flow.

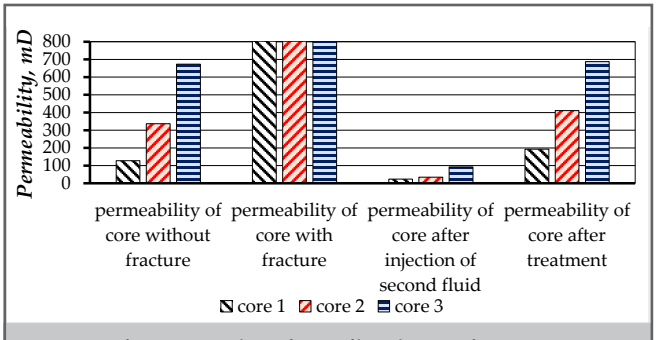

Fig. 2. Results of coreflood experiments

Field application criteria

The described method of bullhead polymer gel squeeze treatment in fractured reservoirs offers advantages over previous attempts, which were associated with risks of damaging oil zones or had limited control over gel propagation pathways. This new method significantly reduces these risks and allows for sufficient gel squeeze into fractures for long-term effectiveness.

It is important to note that this technology is specifically intended for rigless water control in production wells. Other rigless options, such as the Brightwater technology based on swellable polymers or the use of micro gels for injection profile improvement, are more suitable for sweep improvement and water profile control in injection wells [25].

Mechanical methods like setting inflatable packers or squeezing cement into the toe section of the well have been successful in shutting off specific sections of the well, but they are not feasible for shutting off multiple water-producing zones [26, 22].

If successfully implemented in the field, this technology can save production downtime and reduce the cost of water control treatment. Before conducting a field application of this technology, several criteria should be carefully considered. The actual treatment procedure should be based on individual reservoir and well parameters.

Guidelines for the treatment include:

- For vertical wells with a short target interval (5-10 m), bull heading through production tubing can be performed. However, for long intervals or horizontal wells, coil tubing should be used to reach the desired interval. In horizontal wells, focusing on the heel section may be sufficient, but for highly fractured reservoirs with thief zones throughout the open hole segment, segmentation into no more than 200 m segments is recommended using through-tubing inflatable packers and drillable/retrievable bridge plugs.
- A good understanding of permeability contrast and fracture geometry is crucial as this technology relies on the permeability difference between oil-bearing zones (low permeable matrix) and water-producing zones (high permeability fractures). If oil production is mainly from fractures, this technology should not be applied as blocking the fractures will reduce oil production.
- Careful selection of filter-forming particles is essential. Only external filter cakes formed on the hole surface should be allowed, which can be removed mechanically or chemically. Internal filter cake formation due to trapped particles inside the pores can cause irreversible permeability damage. The particle size distribution should be sufficiently narrow, and there is a maximum allowable standard deviation for a given permeability contrast.
- Wellbore cleanup fluid and soaking period should be evaluated in the laboratory to ensure proper filter cake cleanup. Return permeability and well productivity depend on efficient wellbore cleanup.
- Pumping operations should be performed at least 20% below the formation fracture pressure to avoid further complications.
- The fluid properties mentioned above, particularly the gelant fluid, are designed for and compatible with

sandstone formations in specific temperatures. If working with carbonate formations, fluid properties need to be redesigned considering differences in pH, salinity, chemical environment, temperature and etc. that may affect the long-term stability of the sealing gel.

Conclusion

In conclusion, the developed water control technology presented in this study offers a low-cost solution for fractured and high-anomaly wells. The technology is particularly effective when there is a significant permeability contrast between the oil-bearing matrix and water-conductive fractures.

The technology involves a three-stage chemical application process. The first stage aims to protect the oil-bearing matrix, the second stage applies a cross-linking gel to shut off the water-conductive fractures, and the third stage focuses on cleaning the wellbore and restoring matrix permeability.

Core flood experiments were conducted under reservoir conditions using artificially fractured core plugs with different fracture apertures. The results demonstrate a successful blockage of fracture, with minimal contamination of porous medium.

The study also highlights important factors to consider for the field application of this technology. It is recommended to conduct customized laboratory investigations under simulated reservoir conditions prior to implementing the technology in the field. This will help optimize the treatment design and ensure its effectiveness in real-world applications.

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Новый метод изоляция водопритоков на основе временного закупоривающего агента и гелевой композиции

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Реферат

Высокая обводненность продукции на месторождениях является постоянной и сложной проблемой, особенно усугубляющейся при бурении с увеличенным радиусом действия и многоствольных скважин. В данной статье представлена лабораторная разработка новой технологии самоселективного ограничения водопритока без буровой установки. Метод включает в себя разработку и закачку трех различных жидкостей через трещиноватые пробки керна в определенной последовательности. Первая жидкость служит для временной блокировки пористой среды, при этом свободно перемещаясь по трещинам. Вторая жидкость представляет собой сшивающий полимерный гелеобразователь, который закачивается сразу после первой жидкости под давлением ниже давления гидроразрыва пласта для блокирования трещин. Раствор химического разрушителя на основе ферментов, выступающий в качестве третьей жидкости, оценивается для удаления фильтрообразующих материалов. Исследования обработки и притока проводятся с использованием высоконапорной и высокотемпературной установки для притока керна. В итоге, разработанная технология контроля воды, представленная в данном исследовании, предлагает недорогое решение для трещиноватых и высокоаномальных скважин. Технология особенно эффективна при наличии значительного контраста проницаемости между нефтеносной матрицей и водопроводящими трещинами. Результаты демонстрируют успешную блокировку трещины при минимальном загрязнении пористой среды. Исследование также подчеркивает важные факторы, которые необходимо учитывать при полевом применении данной технологии. Перед внедрением технологии на месторождении рекомендуется провести специализированные лабораторные исследования в смоделированных пластовых условиях. Это поможет оптимизировать конструкцию обработки и обеспечить ее эффективность в реальных условиях.

Ключевые слова: водоизоляция; временный блокирующий агент; гелеобразный состав; заводнение керна; контраст проницаемости.

Neft-qaz quyularında izafi suyun izolyasiyası məqsədilə müvəqqəti bloklayıcı reagent və gel tərkibi əsaslı yeni metodun tədqiqi

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Xülasə

İşlənmənin son mərhələsində olan yataqlardan izafi su hasilatı aktual problem olaraq qalmaqdadır. Məqalədə yeni, xüsusi qurğuya ehtiyac olmadan tətbiq oluna biləcək, selektiv izolyasiya texnologiyası təqdim olunmuşdur. Bu texnologiya üç fərqli məhlulun hazırlanması və müvafiq ardıcıllıqla çatlı lay modelinə vurulması haqqındadır. İlk maye məsaməli mühiti müvəqqəti izolyasiya edir və eyni zamanda çatlar boyunca sərbəst hərəkət edir. İkinci məhlul tikilmiş polimer gel məhluludur və hidravlik yarılma təzyiqindən aşağı təzyiqdə çatlı laya vurularaq çatları bloklayır. Üçüncü məhlul, ilk məhlulun yaratdığı müvəqqəti izolyasiyanı özündə həll edərək, məsaməli kanalların yenidən açılmasına səbəb olur. Tədqiqatlar yüksək təzyiq və yüksək temperaturlu lay modeli yaratmaq qabiliyyətinə malik olan avadanlıqda aparılmışdır. Yekun olaraq, çatlı laylar və ya yüksək anomaliyalı quyularda su kanallarının izolyasiyası üçün iqtisadi cəhətdən əlverişli texnologiya təqdim olunmuşdur. Texnologiya yüksək keçirici su kanalları ilə aşağı keçirici neft layları arasında keçiricilik fərqi yüksək olduqda daha effektiv nəticələr verir. Bundan başqa, texnologiya çatların effektiv şəkildə izolyasiyanını təmin etməklə bərabər, məsaməli zonaya minimal təsir edir. Məqalədə həmçinin texnologiyanın mədənlərdə tətbiq zamanı nəzərə alınmalı olan amillərdən bəhs olunur. Həmçinin, mədəndə tətbiq olunmazdan əvvəl tərkiblər laboratoriyada tətbiq olunacaq yatağa uyğun şəraitlərdə testlərdən keçirilməsi məsləhət görülür. Bu sayədə təqdim olunmuş texnologiyanın effektivliyi artırılmış olur.

Açar sözlər: su kanallarının izolyasiyası; müvəqqəti izoləedici reagent; gel tərkibi; lay modeli; keçiricilik arası fərq.