Application of polymer flooding technology for enhanced oil recovery

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Application of brine-initiated gelation of gellan for conformance control and water shutoff operations in field conditions was demonstrated. The developed technology was tested in Kumkol oilfield (Kyzylorda region, Kazakhstan) on five injection wells. According to the results of the first oilfield test, the amount of additionally recovered oil during 11 months (from October 1, 2013 till September 1, 2014) was equal to 5890 tons. In 2014, the JSC "NIPIneftegas" (Aktau city, Kazakhstan) carried out the second pilot test of polymer flooding technology on the same oilfield. The amount of additionally recovered oil during eight months (from October 2014 till May 2015) was equal to 8695 tons. The technology was tested for water shut-off purposes in producing well of Karabulak oilfield. After ten months treatment of production well the amount of water decreased 16 times in comparison with previous results.

Keywords: polymer flooding; water flooding; enhanced oil recovery; pilot test.

Полимерлік суландыру технологиясын мұнай өндіруді жоғарлату үшін қолданысқа енгізу

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Бұл жұмыста айдау ұңғымаларында қабылдау профилін теңестіру және өндіруші ұңғымалардағы су ағысын шектеу мақсатында шаралар жүргізу үшін геллан полимерінің қолданылуы көрсетілген. Әзірленген технология Құмкөл кен орнында (Қызылорда обылысы, Қазақстан) 5 айдау ұңғымасында сыналды. Бірінші тәжірибелік-өнеркәсіптік сынақ нәтижесіне сәйкес 11 ай аралығында (2013 жылдың қазанынан 2014 жылдың қыркүйегіне дейін) қосымша өндірілген мұнай мөлшері 5 890 тоннаға тең. 2014 жылы АҚ «ҒЗЖИмұнайгаз» (Ақтау, Қазақстан) берілген технологияның екінші пилоттық сынағын сол кен орнында жүргізді. 8 ай аралығында (2014 жылдың қазанынан 2015 жылдың мамырына дейін) қосымша табылған мұнай мөлшері 8 695 тоннаны құрады. Бұл технология Қарабұлақ кен орнында өндіруші ұңғыманың су ағысын шектеу мақсатымен сынақтан өтті. Өңдеуден кейін 10 ай өткенде өндірілетін су мөлшері 16 есе қысқарды.

Түйін сөздер: полимерлік суландыру; суландыру; мұнай өндіруді жағарылау; тәжірибелік-өнеркәсіптік сынақ.

Использование технологии полимерного заводнения для увеличения нефтеотдачи

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В работе продемонстрировано применение полимера геллана для проведения операций по выравниванию профиля приёмистости в нагнетательных и ограничению водопритока в добывающих скважинах. Разработанная технология протестирована на месторождении Кумколь (Кызылординская область, Казахстан) на 5 нагнетательных скважинах. Согласно результатам первого опытно-промышленного испытания количество дополнительно добытой нефти за 11 месяцев (с октября 2013 года до сентября 2014) равно 5 890 тон нефти. В 2014 году АО «НИПИнефтегаз» (Актау, Казахстан) провел второй пилотный эксперимент данной технологии на том же месторождении. Количество дополнительно добытой нефти за 8 месяцев (с октября 2014 по май 2015) составило 8 695 тон. С целью ограничения водопритока на добывающей скважине данная технология испытана на месторождении Карабулак. После обработки добывающей скважины в течение 10 месяцев количество добываемой воды снизилось в 16 раз.

Ключевые слова: полимерное заводнение; увеличение нефтеотдачи; опытно-промышленные испытания.

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1. Introduction

Currently one of the most challenging problems of Kazakhstan as well as global oil industry is low oil recovery factor, which does not exceed 30% [1]. In Kazakhstan, 53% of produced oil is presented by mature oilfields. In this respect, increasing oil recovery from these oilfields is a strategic task for economic development of the country. Excessive water production from mature oilfields due to the geological heterogeneity of reservoir rock negatively affects sweep efficiency and oil production. Control of water production in mature water flooded reservoirs may be considered as the most important priority to displace more oil out and decrease water cut [2]. Enhanced oil recovery methods dealing with in-situ redirection of water flow and water production control through changing reservoir properties give second productive life to mature oilfields that would otherwise soon be abandoned [3].

Polymer gel systems have been widely used for water shut off and conformance correction since 1970s. Their intensive application started after Maraphon oil company had successfully tested Marcit gel (HAPA/Cr^{+3}) technology that was developed back in 1972 [4]. During the 1990-1999 acrylamide-polymer/Cr(III)–carboxylate gel was the most widely used system in the world for injectivity profile modifications [5,6]. Copolymer of polyacrylamide tertiary butyl acrylate (PAtBA) crosslinked with polyethyleneimine (PEI) was also widely applied in the field for water conformance control worldwide [7,8]. However, these systems were thoroughly revised and prohibited in some countries because of the negative impact of the crosslinkers on the environment [5].

Other two disadvantages of polyacrylamide gels (PAAG) are low salt tolerance and the fact that the polymer gel systems consist of several components. The fact that PAAG is not stable in the presence of multivalent cations considerably reduces its possible application [9]. In addition, polymer gel system should consist of one component because in this case there is no loss of reagent by precipitation or chromatographic separation. [10,11].

Thus, the oil industry needs a polymer gel system, which should be non-toxic, stable in the presence of salts and consist of one component. Such polymer gel system was developed in laboratory of engineering profile of K.I. Satpaev KazNRTU and private institution “Institute of Polymer Materials and Technology” [12-16]. Starting from 2012, laboratory studies and three field pilot tests were conducted for conformance control and water shut off treatments. Unique property of gellan solution is its ability to form a gel after contacting with brine water (Figure 1). Gellan gels are considered to result from association of double helical stretches at a particular temperature, pH and level of salinity [17].

2. Experiment

Gellan purchased from Zhejiang DSM Zhongken Biotechnology Co., Ltd. (China) was produced from the biomass resulting from the aerobic fermentation of the micro-organism *Sphingomonas elod*ea. Three gellan injection pilot tests were conducted since 2013. Two of these tests were conducted on Kumkol (October 2013 and September 2014), and the third one - on Karabulak oilfield (June 2015). First two pilot tests were conducted by treating injection wells while the third oilfield treatment was conducted in producing well. Plugging agents were widely used for water control in injectors and producers so it was important to adopt practical application of gellan technology for both types of wells. The treatments were conducted by injection of approximately 1 ton of dry gellan powder dissolved in water in the range of concentration 0.1-1%.

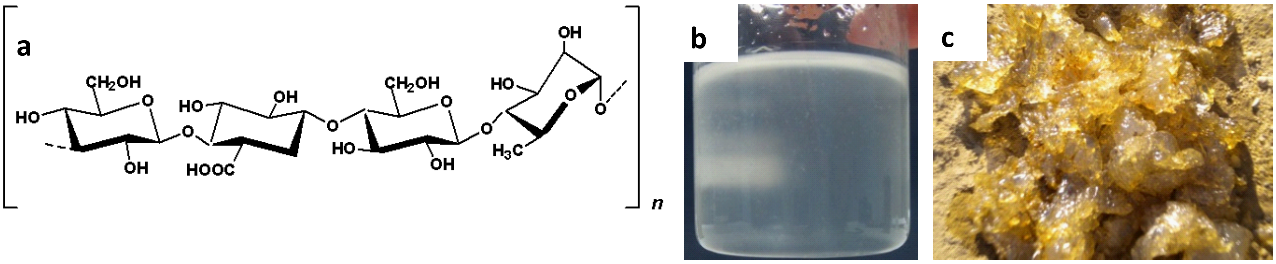

Figure 1 – Structural unit (a) and photos of aqueous solution of gellan before (b) and after contacting with 73 g·L^{-1} salinity reservoir brine (c)

3. Results and Discussion

In October 2013, the first pilot test was conducted on Kumkol oilfield. As a whole, 260 and 150 m^3 of gellan solutions were injected into the U-III reservoir through two injection wells 3383 and 3065 respectively. Successful injection operations was demonstrated by the following curves (Figure 2).

Blue curve represents the instantaneous flow rate of liquid that was constant and equal to 15 m^3/h. Red curve refers to accumulated pumped volume. Dynamics of changing of injection pressure is marked by green curve. At the end of the injection process, the injection pressure in both cases increased up to 90-95 atm, while for this well, initial water injection rate was equal to 15 m^3/h at 50-55 atm. The difference (40 atm) between the injection pressure before and after injection of gellan indicates that the permeability in bottomhole zone of treated wells decreased by pore space plugging.

Results of the treatment were monitored through three producers located in the vicinity of each injector. The best result was demonstrated by producing well 2115 located near to the injector 3065 in which more concentrated solution was injected. For each well, the incremental oil recovery was calculated by comparison of incremental line values with base line value (Figure 3). Base line value is an average oil flow rate calculated during the last three months before the injection. Totally, during 11 months after the treatment, 5890 tons of oil were incrementally produced.

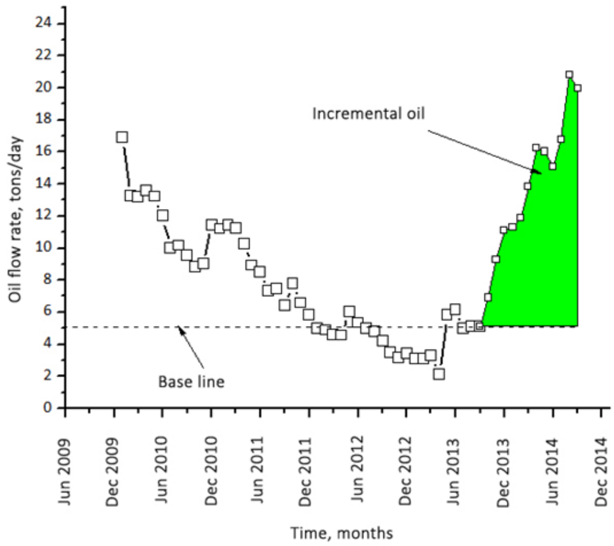

Figure 3 – Integration of oil flow rate curve of producing well 2115

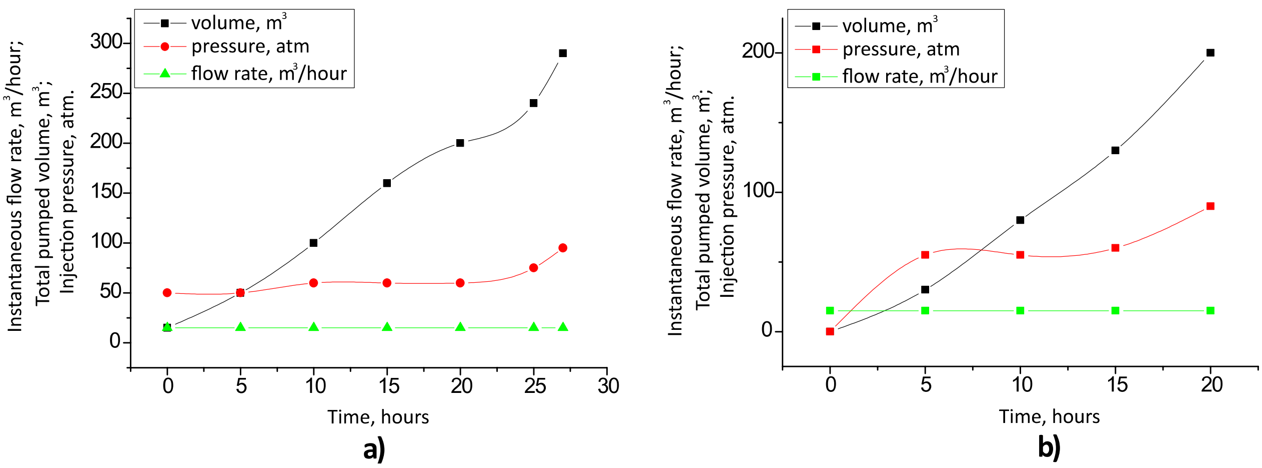

Figure 2 – Instantaneous flow rate, total pumped volume and injection pressure versus time for injection wells: a) 3383 and b) 3065

The second oil field pilot test was conducted on the same oilfield and consisted of the treatment of three injectors. The amount of incremental oil recovery was calculated using of two mathematical methodologies (Tables 1, 2) [18]. The amount of incremental oil recovery produced during eight months (October 2014 – May 2015) was 12 380 and 5 011 tons of oil according to the first and second methodologies, respectively. Thus the averaged amount of incremental oil recovery was equal to 8 695 tons of oil.

Table 1 – The first variant of incremental oil recovery calculation [18]

Method	Incremental oil recovery, tons
Cherepahin-Movmiga	11 567
Ostrovsky-Dzhaparov-1	11 512
Ostrovsky-Dzhaparov-2	11 301
Stasenkov	12 385
Tkachenko	16 245
Average	**12 380**

Table 2 – The second variant of incremental oil recovery calculation [18]

Method	Incremental oil recovery, tons
Pirverdyan	4 377
Nazarov-Sipachev	5 382
Kambarov	6 994
Sipachev-Posevich	4 719
Gaysin	4 695
Average	**5 011**

The effectiveness of the gellan injection was evaluated by comparison of the proposed technology with existing in the world technologies (Table 3). As seen from table 3, injection of 1 ton of dry gellan into the oil reservoirs produced more than 2 800 tons of incremental oil whereas the same amount of other reagents produced 88 – 380 tons of incremental oil. In 2009, the technological efficiency of polyacrylamide (PAAm) on North Buzachi (West Kazakhstan) was 380 tons/ton, and this result was recognized as the best one throughout the world projects. However, the efficiency of gellan was 5 times higher than PAAm in spite of the fact that its cost is 2-3 times higher than PAAm. Thus, the pilot test results on Kumkol oilfield (Kyzylorda region, Kazakhstan) confirmed that the solution to major challenge facing water shut off effectiveness is the excellent gelation ability of gellan in high saline oilfield water and plugging of high permeable channels.

On May 23, 2015, field works at producing well Karabulak-34 were started. Before the treatment, the well was characterized by current oil flow rate – 17 tons/day, water cut percentage – 77%, daily production of water – 62 tons/day; perforated intervals through which the well was connected with the reservoir – 1395-1397 m, 1398.5-1405 m, 1408.5-1412 m. Figure 4 shows that during the last 5 months, water cut increased from 16 up to 77% while the well produced the liquid with a flow rate 80 tons/day. It was expected that the injection of gellan solution into the Karabulak-34 producing well will decrease the water cut and increase oil recovery rate.

All works were conducted in 5 steps:

1. Identification of water bearing layers.

In order to direct injected gellan solution into the water bearing formations the geophysical survey was provided to identify the watered out layers.

2. Connection of the well with water bearing layers and its isolation from oil saturated strata.

Watered out layers were disjoined with oil bearing formations by injection of concrete into the well that was drilled through and layers that mainly contribute to the water production were perforated for consequent injection of gellan solution.

Table 3 – Comparative analysis of the effectiveness of gellan with tested polymer flooding technologies

Oil field/Used reagent	Number of injection wells	Amount of reagent, (tons)	Incremental oil recovery, (tons)	Technological efficiency*, (tons/ton)	Time, (months)
Kumkol/Gellan	2	2	5 890	**2945**	11
Kumkol/Gellan	3	3	8 695	**2898**	8
Buzachi/PAAm[19]	1	42	16 000	**380**	12
Daqing/PPG[20]	4	134	15 000	**113**	10
Zhon-gyuan, PPG[21]	2	20.5	3239	**158**	3
Usinskoe/Galka[22]	no data	117	10 316	**88**	6

*Technological efficiency is a ratio between the amount of incremental oil recovery and the amount of used reagent.

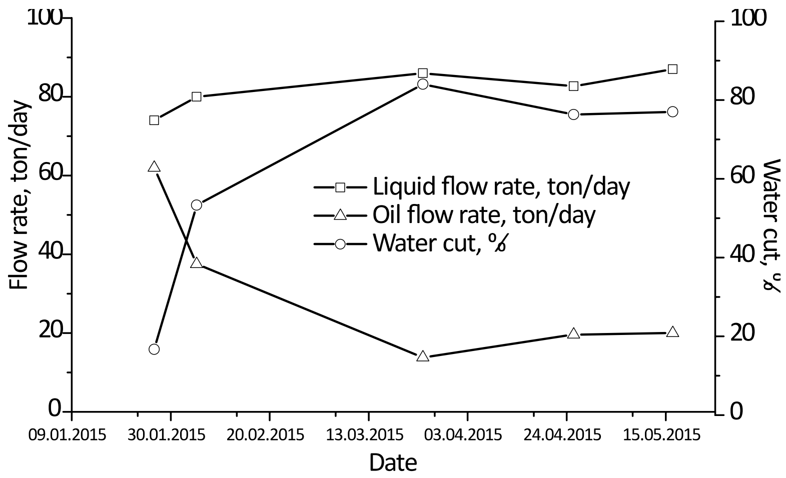

Figure 4 -– Production history of the well K-34

Perforations specified for the injection of gellan solution were made in the following intervals 1404.5-1405.5 m, 1413-1414 m.

3. Increasing deliverability of the well for the injection of gellan solution.

Water injection capacity of upper and lower perforation intervals was measured and was equal to 173 tons/day and 43 tons/day, respectively; thus total deliverability of the well was equal to 216 tons/day. In order to increase this value, the well was subjected to acid treatment, 2.2 m^3 of acid solution were injected into the well followed by the injection of 4.6 m^3 of technical water. After the acid treatment, the deliverability of the well was measured again and showed to be increased at least two times – 480 tons/day.

4. Injection of gellan solution.

During 2 days, 120 m^3 of 1% gellan solution were injected into the well K-34, the injection process was characterized by initial (70 bar) and final injection pressure (100 bar).

5. Reconnection of the well with oil saturated strata.

After injection of gellan, the well was washed out by technical water and filled out with concrete solution at the interval between 1390-1415 m. Next operations included the drilling of concrete cement plug, perforation of intervals 1395-1397 m, 1398.5-1403 m, 1408.5-1411 m through which the well will be exploited by using electrical submersible pump unit.

The first results of well treatment are presented in Figure 5.

As seen from Figure 5, after the treatment of the well by gellan solution, the amount of produced water decreased about 16 times while the oil flow rate did not change considerably. Tremendous decrease of water cut will allow the oil companies to save considerable amount of money spent for water transportation and separation. In addition, the decrease of water production has a positive impact on an environmental protection.

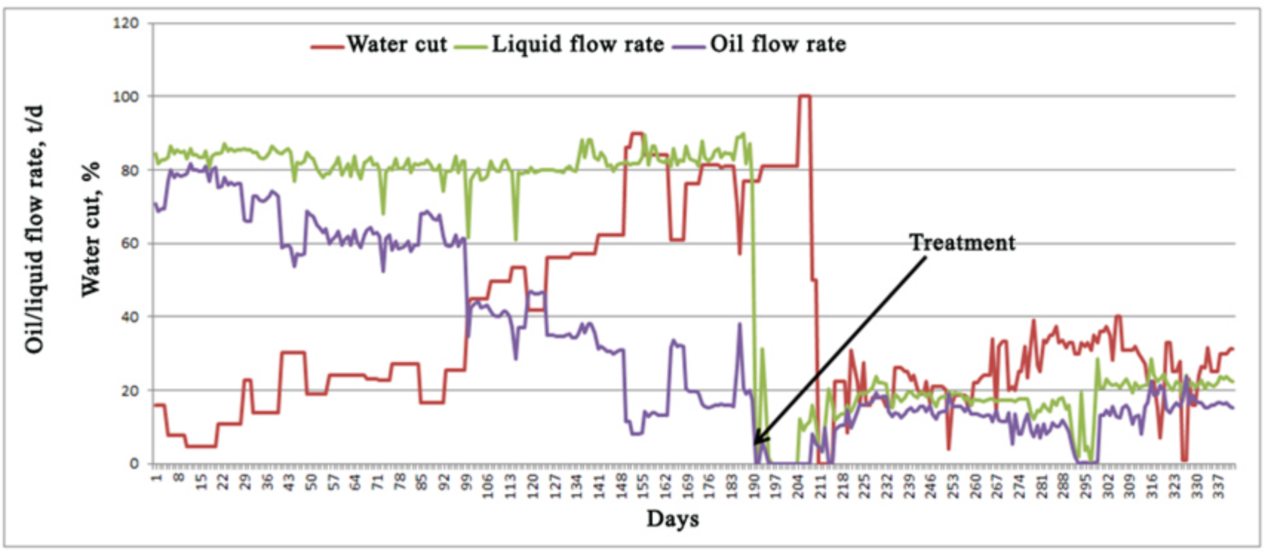

Figure 5 – History of production characteristics of the well K-34

4. Conclusion

Effectiveness of using gellan as an agent for conformance control operations was demonstrated twice in real oilfield conditions. As a result of treatment of 5 injection wells during 19 months, 14 585 tons of incremental oil were produced. One ton of dry polymer allowed producing more than 2 800 tons of incremental oil. Pilot test conducted in Karabulak oilfield confirmed that the technology may be effectively used for water production control. Treatment of the producing well K-34 decreased the amount of produced water 16 times. It is expected that the proposed technology is interesting for domestic and worldwide oil industry.

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