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Application of Polymer Gellan for Injectivity Profile Leveling

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Abstract

This work describes the results of laboratory experiments carried out on core samples and sandpack models as well as the field pilot tests conducted in October 2013 on 2 injection wells of Kumkol oilfield. The reduction of the permeability of porous space was achieved by injection of gellan solution, gelation of which is initiated by the following cations: Ba^{2+}, Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, containing in brine water. On the basis of laboratory experiments the suitable concentrations of polymer reagent for the pilot tests were selected. A series of laboratory experiments were carried out to reduce the amount of polymer reagent without detriment to the efficiency of the technology. Also the mixtures of polysaccharides gellan and xanthan in the weight ratios 1:2; 1:1; 2:1 were found to be more effective in comparison with separate components. One of the main features of this work is that polysaccharide gellan was used for the first time in oil industry, thus new application frontier for this polymer was found. The most remarkable feature of the proposed polymer is due to its gelation after contacting with brine water so no additives are needed to initiate the gelation process inside of the oil formation in contrast to polyacrylamide gels crosslinked by chromium ions which are widely used for conformance control operations.

Introduction

As world population approaches to 7.5 billion people the consumption of energy resources constanly growth. To meet this demand petroleum companies are trying to find new methods for the extraction of undrained oil from mature oilfields. Mature fields give more than 70% of the world's hydrocarbon production while the average recovery factor for oil is only 35%, thus increase of the recovery factor from these reservoirs is common target for petroleum companies [1]. Maintainance of reservoir pressure in oilfields is achieved by water injection. Water encroachment pattern is not always evenly distributed throughout the heterogeneous strata and as a result water breakthrough takes place in the production wells. Excess production of water through localized super-permeable channels is one of the main problems which have to be addressed in order to increase recovery factor for oil [2].

To increase macroscopic sweep efficiency of a reservoir, water injectivity profile should uniformly spread across the entire reservoir. This may be achieved by plugging of those super-permeable channels

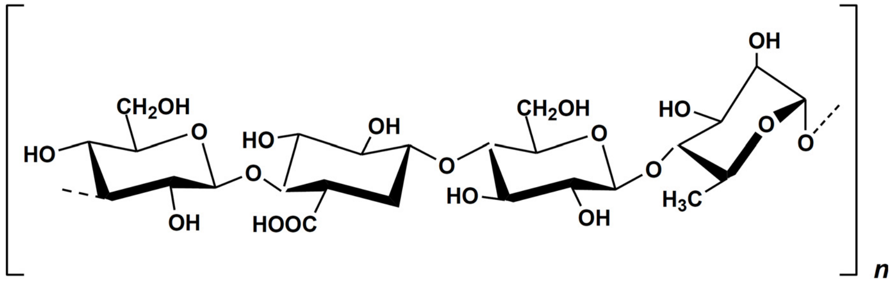

Figure 1—Structure of the repeating monomer unit of gellan

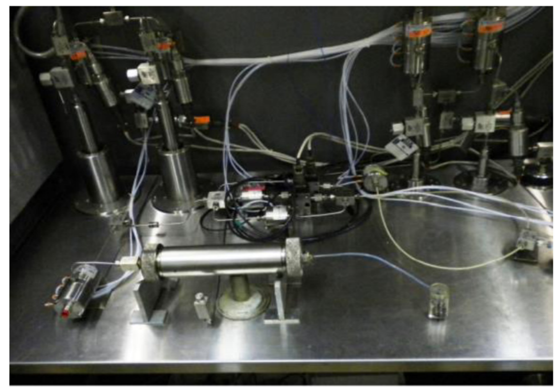

Figure 2—Sand pack molel for investigation of gellan plugging properties under reservoir conditions

and by redistribution of waterdrive into low permeability areas mobilizing hard-to-move pockets of unswept hydrocarbons [3]. For this aim polymer solutions have been used extensively. Injected polymer solution generally penetrates into high permeable zones and the relative permeability reduction takes place after the solution has been swelled or crosslinked *in situ* [4, 5]. Literature survey shows that a wide variety of polymer gel systems generally consist of: inorganically crosslinked and organically crosslinked polymer gels [6]. Partially hydrolyzed polyacrylamide (PHPA) crosslinked by Cr^{+3}, Zr^{+4} and Al^{+3} is one of the examples of inorganically crosslinked gels that are widely used since 1970s [3]. Example of organically crosslinked polymer gel is copolymer of polyacrylamide tertiary butyl acrylate (PAtBA) crosslinked with polyethyleneimine (PEI) was also widely applied in the field for water conformance control worldwide [6, 7]. But these systems were thoroughly revised and prohibited to be used in some countries because of the negative impact of the crosslinkers on the environment [8]. Because of these issues, finding and practically adopting an environmentally friendly, single component polymer gel system is a focus of this study.

Experimental part

Materials and methods

In this study the newly introduced polymer is anionic extracellular polysaccharide gellan discovered in 1978. Gellan consists of tetrasaccharide units: 1,3-linked β-D-glucose, 1,4-linked β-D-glucoronic acid, 1,4-linked β-D-glucose, and 1,4-linked α-L-rhamnose as shown in Fig.1.

Aqueous solution of gellan undergoes sol-gel transition under certain temperature, pH and salinity [9, 10], this remarkable feature makes this polymer attractive for water profile leveling applications. Xanthan is an extracellular polysaccharide produced by fermentation of the bacterium *xanthomonascampestris*. Its low cost, high viscosifying ability, coupled with excellent stability under high salinity, high temperature, and mechanical shear conditions makes it suitable for enhanced oil recovery (EOR) [11]. Xanthan gum was kindly furnished by Xinjiang Fufeng Biotechnologies Co., Ltd. (Urumqi, China). Fluid samples used were brine water and crude oil from Kumkol oilfield (Republic of Kazakhstan). Brine water with density 1.05 g cm^{-3} and pH 6.68 was composed of 22.5 $g{\cdot}L^{-1}$ of Na^+ and K^+, 3.8 $g{\cdot}L^{-1}$ of Ca^{2+}, 0.85 $g{\cdot}L^{-1}$ of Mg^{2+}, and 43.9 $g{\cdot}L^{-1}$ of Cl^- ions. Crude oil density and dynamic viscosity at 55 °C were 795.4 kg m^{-3} and 2.679 mPa·sec respectively. Steel cylinder filled with sand was used to simulate the porous medium (Fig.2). These sand packs were composed of sand particles with granular size varying from 0.043 to 1 mm.

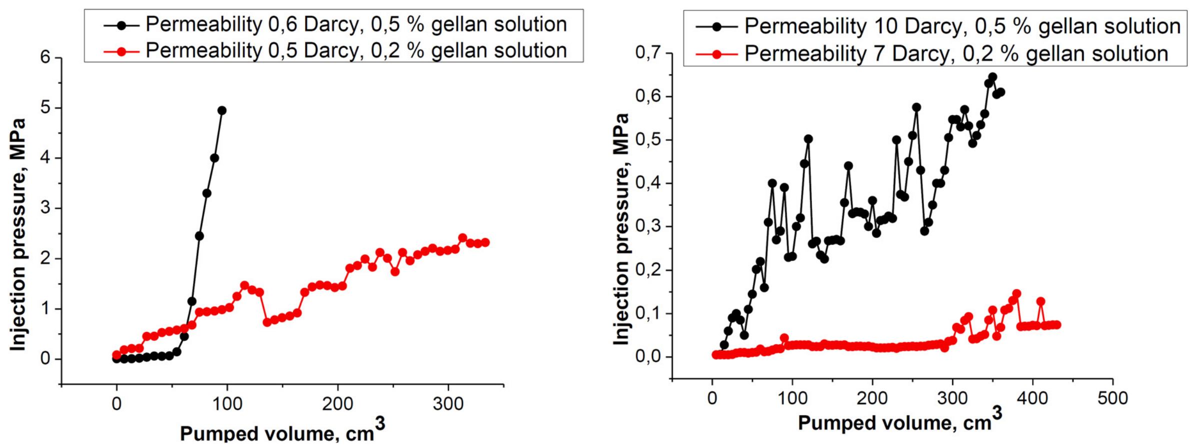

Figure 3—Changing of injection pressure versus injection of 0.2 and 0.5 % gellan solutions

In each case gellan solution was injected into the previously waterflooded sand pack model. Water, oil and polymer solution were injected under the flow rate of 0.5 $cm^3 \cdot min^{-1}$. And the injection pressure value was constantly registrated.

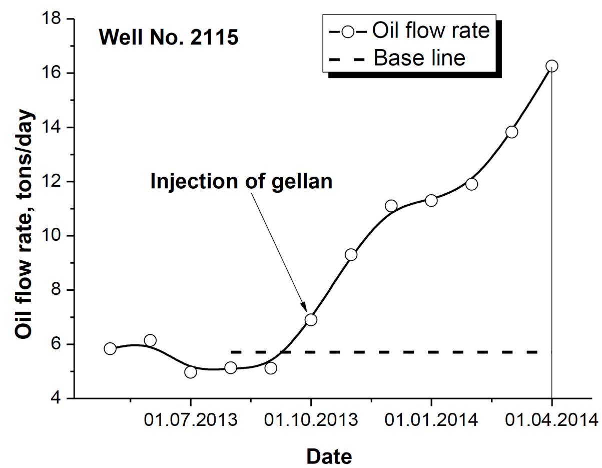

Figure 4—Response of the production well No. 2115 to the injection of gellan solution

Results and Discussion

Laboratory testing for injectivity profile leveling operation (IPLO)

Analysis of the injection pressure curves allowed to reveal some peculiarities in hydrodynamic behavior of gellan aqueous solution which distinguish it from the other polymers used in oil industry and also to choose an appropriate concentration of the solution for the oilfield pilot tests.

The first series of experiments were aimed to select the appropriate concentration of gellan solution for the injectivity profile leveling operation (IPLO) in two injection wells on Kumkol oilfield. The pilot tests were conducted in two steps: 1) injection of low concentrated gellan solution to increase the overall sweep efficiency of the reservoir and to create gel plugged areas on the long distance from the injected well; 2) injection of high concentrated gellan solution to level the water injection pattern (profile) in the vicinity of the well. In our case 0.2 and 0.5 % gellan solutions were tested on the sand pack models, the experimental results are given in Fig. 3.

It is seen that independently on the permeability of sand pack model the higher concentration of gellan demonstrates the better plugging effect. Therefore it is suggested that 0.2% gellan solution is better to use for in depth permeability modification. While the 0.5% gellan solution is better to use as a permeability modifier in the vicinity of the injection well.

Performing of the field pilot tests

Aqueous solution of gellan was injected into two injection wells (No.3383 and 3065) on Kumkol oilfield, the total volumes of injected solution were 234 and 160 m^3, respectively. One ton of dry polymer powder was spent for each well. In the course of injection of gellan solution the pressure increased from 55 to 90-95 atm indicating the reduction of the permeability inside of the reservoir. Response of the reservoir to the treatment was monitored through 6 producing wells located in the neighbourhood of the injectors. Effectiveness of the technology was estimated after 6 months. For each well the incremental oil recovery

Table 1—Incremental oil recovery values calculated for each well

Number of the well	Tons of incremental oil recovery
2158	1028,6
2342	- 730,7
3084	654,4
3064	238,9
2315	739,6
2115	1129,2
Total	**3790**

Table 2—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	3 790	1 895	6
Buzachi/PAAm[12]	1	42	16 000	380	12
Daqing/PPG[13]	4	134	15 000	113	10
Zhon-gyuan, PPG[14]	2	20,5	3239	158	3
Usinskoe/Galka[15]	no data	117	10 316	88	6

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

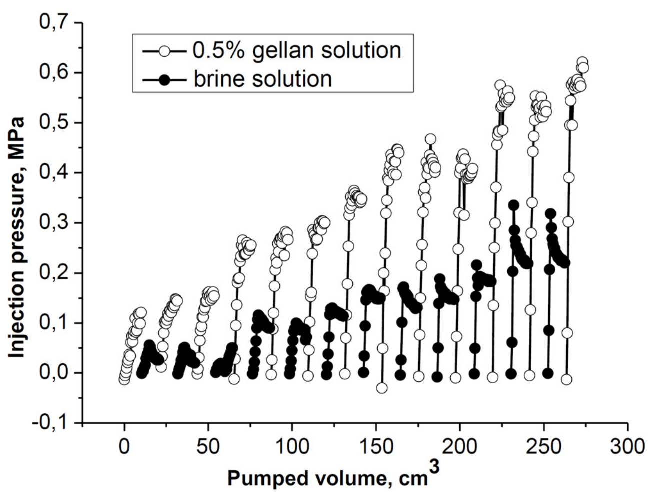

Figure 5—Alternating injection of 0.5% gellan and brine solutions

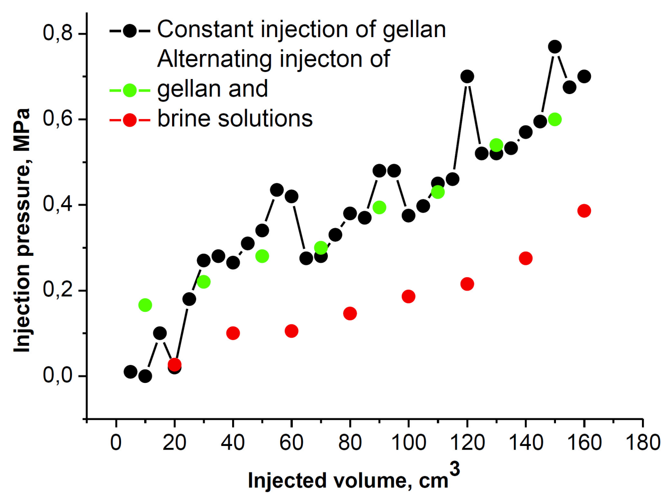

Figure 6—Comparison between separate injection of gellan solution and alternating injection of gellan and brine solutions into the sand pack model

was calculated by comparison of incremental line values with base line value. Base line value represents an average oil flow rate calculated for the last three months before injection. Base line oil flow rate value is extrapolated to the next 6 months after the treatment, and then this value is subtracted from the total value of really produced oil during this period of time. The well 2115 showed the most optimistic response to the treatment compared to the prehistory of oil flow rate (water flooding) (Fig. 4).

The incremental oil recovery for each well is presented in Table 1.

The negative increment for the well 2342 is explained by the fact that this reservoir has been waterflooded for more than 20 years, injection of gellan led to enhancement of oil production and to more severe depletion of the part of the reservoir adjacent to the injectors.

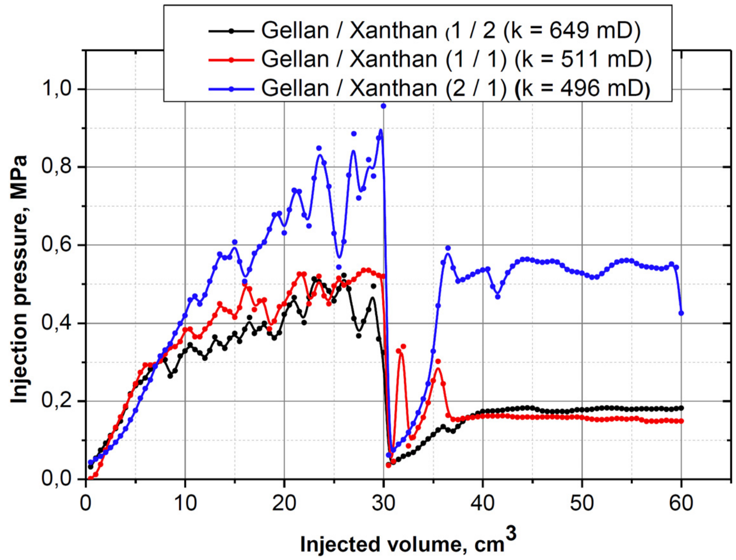

Figure 7—Results of core flooding experiments by gellan:xanthan mixtures

The effectiveness of the gellan injection was evaluated by comparison of the proposed technology with existing technologies (Table 2).

As seen from table 2, injection of 1 ton of dry gellan into the oil reservoirs produces 1 895 tons of incremental oil whereas the same amount of other reagents produces 88 - 380 tons of incremental oil. In 2009 the technological efficiency of polyacrylamide (PAAm) for IPLO 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 is 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 permeabile channels.

Alternating injection of gellan and brine solutions

Unique property of gellan is to form gel structure through contacting with brine water. Therefore alternate injection of gellan and brine water into the oil reservoir is expected to be more effective plugging way of high permeable channels. Since the gellan powder is dissolved in technical water with low salinity, the constant injection of gellan solution leads to the washing out of salt from the vicinity of the well. The gel formation takes place when the front edge of injected gellan solution meets the saline water (so called sol-gel transition) [16]. Due to permanent injection of gellan solution into the well the salinity of oil reservoir gradually decreases. In its turn this causes formation of flowable weak gel that reduces the efficiency of plugging. It is expected that alternate injection of gellan and brine solutions will overcome this problem. To check this point a series of filtration experiments were conducted on sand pack models possessing the high permeability 2 Darcy. Experiments consisted of alternating injection of 10 cm^3 of 0.5 % gellan solution and brine water into the waterflooded sand packs. The dependence of injected pressure on pumped volume was compared with constant injection of gellan (Fig.5).

It is clearly seen from Fig. 5 that each portion of injected gellan solution is followed by the injection of brine water portion. Alternate injection of gellan and brine solutions leads to gradually increase of the injection pressure. The reasonable explanantion of this phenomenon is permanent formation of gel slug inside of the sand pack. Fig. 6 clearly demonstrates that alternate injection of gellan and brine solutions gives the same effect if only gellan solution will be injected. The difference between the constant injection of gellan and alternating injection of gellan and brine solutions is small in the context of pore space plugging.

Thus by the alternating injection of gellan and brine solutions it is possible to reduce the amount of injecting reagent at least two times without detriment to the efficiency of the technology. This approach will considerably reduce the cost of the project.

Injection of gellan and xanthan mixtures

One of the disadvantages of gellan is its high cost. So it is worthy to study whether mixture of gellan and xanthan is applicable for conformance control or not. To decrease the total cost of the polymer flooding technology the mixtures of gellan and xanthan with weight ratios of [gellan]:[xanthan] = 2:1; 1:1 and 1:2 were tested. Three core flooding experiments were conducted to study the dynamic plugging properties of aqueous solutions of gellan and xanthan mixtures (Fig.7). The concentration of gellan and xanthan mixtures was kept constant and equal to 0.5%.

Aqueous mixtures of gellan and xanthan prepared at the weight ratios of 1:1 and 1:2 behave similar plugging properties while excess of gellan component in the mixture (2:1) shows the better plugging ability and may be used for conformance control. For the low permeability rocks it is recommended to use the mixtures of [gellan]:[xanthan] with weight ratios 1:1 and 1:2 while for conformance control of the high permeable channels the mixture of [gellan]:[xanthan] = 2:1 should preferentially be used. From economic point of view the application of the mixtures of gellan and xanthan reduces the cost of reagents by 22%.

Conclusions

The unique property of gellan to form gel through contacting with salt may be applied for alternating injection of gellan and brine slutions to create the gel slugs inside of the reservoir. As a result the cost of polymeric reagent may be reduced two times. Depending on in-place permeability the optimal composition of gellan and xanthan may be used for the plugging of high or low permeable channels. Enriched by gellan mixture is effective for plugging of high permeable zones. Equimolar or enriched by xanthan mixture is suitable for conformance control of low permeable channels. Moreover, the application of the mixtures of gellan and xanthan reduces the cost of reagent by 22%. The results of pilot test conducted at Kumkol oilfield showed that polysaccharide gellan can be adopted as a new highly effective IPLO agent for injection wells on mature oilfileds. Efficiency of gellan was compared with existing polymer gel systems used in oil industry. Comparative analysis demonstrates that the effectiveness of gellan is 5 times higher than the best result resgistrated in 2009. It is expected that our laboratory and oilfield tests will open a new world for environmentaly friendly gellan application in EOR.

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References

1. *Maximizing the Value of Mature Fields*. 05/2012 HALLIBURTON, Solving challenges.
2. Toshiya O., Hiroshi O.: "*Early water breakthrough in carbonate core samples visualized with x-ray*." SCA2000-08.
3. Borling D., Chan K., Hughes T., Sydansk R.: "Pushing Out the Oil with Conformance Control." *Oilfield Review*. April 1994.
4. P.D. Moffitt: "Long-Term Production Results of Polymer Treatments in producing Wells in Western Kansas." SPE-22649-PA, *Journal of Petroleum Technology* **04**/1993.
5. A. Zaitoun, N. Kohler, D. Bossie-Codreanu, K. Denys: "Water Shutoff by Relative Permeability Modifiers: Lessons from Several Field Applications." SPE-56740-MS, SPE Annual Technical Conference and Exhibition, 3-6 October, Houston, Texas 1999.

6. Dr. Ghaithan A. Al-Muntasheri, Leopoldo Sierra, Francisco O. Garzon and Jack D. Lynn: Water Shut-off with Polymer Gels in a High Temperature Horizontal Gas Well: A Success Story *SAUDI ARAMCO JOURNAL OF TECHNOLOGY* SUMMER 2010.
7. Larry S. Eoff, Eldon D., Don M. Everett, Julio E. Vasquez.: “Worldwide Field Applications of a Polymeric Gel System for Conformance Applications” SPE-98119-MS, SPE International Symposium and Exhibition on Formation Damage Control, 15-17 February, Lafayette, Louisiana, USA 2006.
8. B.R. Reddy, Larry Eoff, Dwyann D., Kathy B., Brown D. Rietjens M.: “A Natural Polymer-Based Cross-Linker System for Conformance Gel Systems.” SPE-84937-PA, *SPE Journal* **02**/2003.
9. Manjanna, K.M.; Pramod Kumar, T.M.; Shivakumar, B. *Int. J. Chem. Tech Res.* **02**/2010.
10. Morris, E.R.; Nishinari, K.; Rinaudo M. *Food Hydrocolloids*. **28**/2012.
11. Liu, Y.Z., Tian, J., Li, W.D., Guo, X.H. Pilot Test of Xanthan Gum Flooding in Shengli Oilfield. SPE Asia Pacific Improved Oil Recovery Conference, 25-26 October 1999, Kuala Lumpur, Malaysia.
12. Ч. Сунь, И. Шагирбаев, С. Лобанов и др.: “Научно прикладные аспекты проекта по гелеполимерному заводнению на месторождении Северные Бузачи.” ООО «РН-УФАНИПИНЕФТЬ».
13. Baojun Bai, Fusheng Huang, Yuzhang Liu, Yefei Wang: “Case Study on Preformed Particle Gel for In-depth Fluid Diversion.” SPE 112997, SPE Symposium on Improved Oil Recovery, 20-23 April, Tulsa, Oklahoma, USA 2008.
14. Baojun Bai, Liangxiong Li, Yuzhang Liu, He Liu, Zhongguo Wang and Chunmei You: “Preformed Particle Gel for Conformance Control: Factors Affecting Its Properties and Applications.” *SPE-89389-PA, SPE Reservoir Evaluation & Engineering* **04**/2007.
15. Алтунина Л., Кувшинов В.: “НИНКА, ГАЛКА и РОМКА увеличат добычу нефти.” Журнал «Мировая энергетика» Июнь 2004 г.
16. S. Kudaibergenov, N. Nuraje, Zh. Adilov, D. Abilkhairov, R. Ibragimov, I. Gusenov, A. Sagindykov. Plugging behavior of gellan in porous saline media. *J. Appl. Polym. Sci.* 2014, V.**131,** published online: 8 AUG 2014 DOI: 10.1002/app.41256.