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Short communication

Application of microbial enhanced oil recovery technique to Daqing Oilfield

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Abstract

Pseudomonas aeruginosa (P-1) and its metabolic products (PIMP) of 10% could enhance the oil recovery in the model reservoir by 11.2% and also decrease injection pressure by 40.1%. Further, PIMP (10%) could reduce the crude oil viscosity by 38.5%. In the pilot tests, about 80% of wells used showed a significant increase in crude oil production after PIMP injection and shut-in for about 1 month. The pilot tests also revealed that PIMP could prolong cycle of oil well washing so that the total oil production increased.

Keywords: Microbial enhanced oil recovery; Reducing crude oil viscosity; *Pseudomonas*

1. Introduction

After primary and secondary recovery procedures, there is still much residual oil trapped in the rock pores. Microbial enhanced oil recovery (MEOR) is a technique to utilize microorganisms and their metabolic products to improve the recovery of crude oil from reservoir rocks [1,2]. There are many approaches by which the microorganism injected into oil reservoirs can improve oil recovery efficiency. One of which is the production of biosurfactants that can increase oil production by lowering the interfacial tension at the oil–rock interface. The lowered interfacial tension reduces the capillary forces that prevent oil from moving through rock pores [3].

Daqing Oilfield is the biggest oil field in China. Its reservoir is at an average depth of 1400 ft. The average porosity is 16% and the average effective thickness is 9.2 m. The wax content in the crude oil is about 20%. The temperature of the reservoir is about 45 °C, which fits for MEOR. Although many approaches of EOR have been applied to Daqing Oilfield, the MEOR has an excellent prospect due to its benefits and the natural conditions of this oilfield.

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PIMP could serve as a biosurfactant, and reduce the crude oil viscosity to prolong the cycle of washing wells (CWOW). In the laboratory tests, we stimulated oil from the model reservoirs with PIMP instead of the traditional waterflooding. The application of MEOR in pilot tests in Daqing Oilfield was also investigated in this study.

2. Materials and methods

2.1. Materials

Microorganism. The microorganism used for the experiments was isolated from the water contaminated by the crude oil and identified as *Pseudomonas aeruginosa* (P-1). The medium contained the following, in grams per liter of water: glucose, 20; peptone, 2; Na_2HPO_4, 2; $(NH_4)_2SO_4$, 2; KH_2PO_4, 3; $MgSO_4$, 2; $CaCl_2$, 0.05; pH 7.2. P-1 was cultivated in this medium for about 48 h.

Crude oil. The crude oil was obtained from Daqing Oilfield. Its viscosity is 6.7 MPa. It was left at 45 °C overnight and the water mixed with the crude oil was separated from oil.

Model reservoirs. The model reservoirs were 30 cm in length and the volumes were 600 cm^3. The experimental equipment used was an adaptation of that described by Kemal et al. [2].

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3. Methods

3.1. Experimental procedure

The laboratory experiments were run as follows. The model reservoirs were completely packed with crushed limestone, and a vacuum was applied for about 2 h. After this operation, these model reservoirs were brined with 18,000 ppm NaCl and then saturated with the crude oil. We stimulated these model reservoirs with water until the proportion of water came out from the outlets was 90%. Then, a different diluent of PIMP instead of water was used in the experimental model (EM) to stimulate the oil. At the same time, the referential model (RM) was still stimulated with water as before. The oil recovery rate enhanced in EM was in comparison with that of RM. These model reservoirs were kept under the condition of 45 °C and the injection pressure was controlled to ensure that P-1 or water was injected into EM and RM at a rate of 20 cm^3/h.

The pilot tests were conducted as follows. (i) The pilot test for enhancing the oil recovery. The experimental wells with PIMP injection and the observation wells without the material above injection were shut-in for 1 month, then still stimulated with water. The results examined were respectively compared with the previous records. (ii) The pilot test for prolonging CWOW. The wells for this experiment were injected with PIMP and not shut-in. The CWOWs measured in the experiments were compared with the previous cycles.

3.2. Measurements

The following measurements were made for the experiments. Oil viscosity, by cone and plate viscomer made in Germany; interfacial tensions (IFT) between crude oil and PIMP, by Texas 500 interfacial tensionmeter made in USA; surfacial tensions (SFT) of PIMP, by JYZ 200 interfacial tensionmeter made in China.

4. Results and discussion

4.1. Laboratory tests

The IFT, SFT and the oil viscosity decreasing rate would be 0.65×10^{-2} mN/m, 27.3 mN/m and 38.5%, respectively, when the concentration of PIMP was 10%. The results demonstrated that the IFT, SFT and oil viscosity decreased with an increase in the concentration of PIMP. Also, the byproducts of P-1 were stable at different temperatures and the IFT was still 5.2×10^{-2} mN/m after PIMP (10%) were left at 70 °C for 16 h, which suggests that PIMP can serve as a surfactant and is applicable to the reservoirs whose temperatures are below 70 °C.

The results (Table 1) showed that the oil recovery could be enhanced when different concentrations of PIMP were used to stimulate the crude oil from EM. Although the porosities of EM-8 and EM-9 were nearly the same, their injection pressures (before MEOR) to ensure water or P-1 injected at a rate of 20 cm^3/h were quite different. We could also see the similar phenomenon from the injection pressures of EM-7 and EM-10 before MEOR. The injection pressure had no clear relationship with the porosity owing to the structure complexity of the model reservoir [4]. Furthermore, because the porosities are all different in the model systems, it is not possible to compare the effect of PIMP concentration on the enhanced recovery. However, the decreasing rate of injection pressure increased with an increase in the concentration of PIMP. The results obtained provide a conclusion that PIMP was effective in improving the oil recovery efficiency and saving injection energy.

4.2. Pilot applications

More than 60 oil-producing wells had been injected with PIMP compared with six observation wells. In about 80% of the injected wells, the oil production increased after

Table 1
The result of MEOR in model reservoirs[a]

Model No.	Porosity of model (%)	Concentration of PIMP (%)	Recovery enhanced (%)	Injection pressure before MEOR (atm)	Injection pressure after MEOR (atm)	Decreasing rate of injection pressure (%)
RM-1	19.2	0	0	5.8	5.6	0
RM-2	19.8	0	0	5.0	4.8	0
EM-3	23.7	15	9.5	2.84	1.7	40.1
EM-4	22.6	15	10.3	3.15	2.0	36.5
EM-5	24.3	10	11.2	3.95	2.6	34.2
EM-6	23.5	10	9.8	3.9	2.5	35.8
EM-7	25.0	5.0	5.1	5.5	3.7	21.7
EM-8	20.6	5.0	8.5	5.8	4.0	20.3
EM-9	20.0	2.5	10.2	6.0	4.5	14.0
EM-10	25.8	2.5	9.8	4.6	3.4	15.0
EM-11	20.3	1.0	6.3	4.5	3.7	6.7
EM-12	20.1	1.0	7.2	4.8	4.0	5.6

[a] PIMP: P-1 and its metabolic products; EM: experimental model stimulated with PIMP; RM: referential model stimulated with water. Decreasing rate of injection pressure (P_D) may be expressed as: $P_D = ((P_{Eb} - P_{Ea})/P_{Eb}) - ((P_{Rb} - P_{Ra})/P_{Rb})$. P_{Eb} and P_{Rb} are injection pressures of EM and RM before MEOR, respectively. P_{Ea} and P_{Ra} are injection pressures of EM and RM after MEOR, respectively.

1 month shut-in period. The results showed that the water content of well Zhao 96-70 decreased greatly although the liquid production per day was not changed. The crude oil production increased from 3 t before injection to 12 t after injection. The conditions of low water content lasted for more than 40 days and the conditions of other injected wells were similar to those of well Zhao 96-70. In contrast, the liquid and oil productions of the observation wells did not change obviously.

From the pilot tests it could also be seen that PIMP could prolong CWOW of the experimental wells after PIMP injection. The reason for the prolonged CWOW may be explained as PIMP prevented wax deposition on the wells' walls by reducing the oil viscosity. The liquid production per day of the well Team 5-5 increased after P-1 injection, but the oil production was stable. Thus, the total oil production of the well Team 5-5 increased because its CWOW (79 days before injection) was prolonged to 179 days. Also, the average current measured while running the well Team 5-5 decreased after P-1 injection, which demonstrated that a lot of energy was saved.

In this paper, we used PIMP as a biosurfactant [5] under the condition of shut-in oil wells. In addition, PIMP could prolong CWOW. The main mechanism is believed to be that PIMP can reduce the IFT and the oil viscosity. The results obtained from the tests demonstrated that P-1 had a great application potential in Daqing Oilfield. Other factors that affect the enhanced oil recovery and other mechanisms involved in MEOR require further research.

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