The research of relative permeability curve for microbial flooding in Baolige oilfield

Shasha Liu¹*, Yaxiu Fu², Yi Gu⁴, Rui Wang¹, Guan Wang¹, Lisha Duan¹, Suzhen Guo¹, Lili Wei¹

¹ Engineering Technology Research Institute, Huabei Oilfield Company, Renqiu, Hebei, 062552, China
² Erlian Branch, Huabei Oilfield Company, Xilinhot, Inner Mongolia, 026000, China
*Corresponding author’s e-mail: cyy_liuss@petrochina.com.cn

Abstract: To adequately simulate environment of Baolige oilfield reservoir, research the seepage variation of microbial in the reservoir, we selected the current microbial flooding system, nature core, dehydration crude oil and injection water of Baolige oilfield. And the evaluation experiments of microbial flooding system and the relative permeability experiments of water flooding and microbial flooding were carried out. Results showed that the flooding system had obvious effect to reduce the emulsification, viscosity and IFT. Comparing to the water flooding, the two-phase seepage area expanded, oil phase permeability endpoint shifted to the right, and residual oil saturation decreased when using microbial flooding. The water phase permeability decreased and the oil phase permeability increased. The relative permeability in the isotonic point changed little, but shifted to the right. Microbial flooding anhydrous recovery period was longer, and the anhydrous recovery rate was higher. In the condition of the same injection, microbial flooding had higher degree of reserve recovery and the displacement pressure was lower. The experiment results fully reflected the two-phase flow in the microbial flooding process, and provided important parameters and basic basis for the prediction and effect evaluation of microbial flooding.

1. Introduction

MEOR technology is a technology that achieves enhanced oil recovery by directly or indirectly acting on reservoir and reservoir fluid by microorganisms and their metabolites. Compared with other EOR technologies, MEOR technology has the advantages of low cost, simple process, wide application and environment friendly. At present, this technology is being paid more and more attention by oilfield production units. Multiple oilfields in our country have conducted related field experiment [1-3]. Microbial laboratory experiments are mostly based on microbial laboratory evaluation. Emulsification and viscosity reduction tests are carried out to evaluate the effects of microbial and crude oil [4-6]. In the aspect of physical model experiment, the simulated core is generally used to carry out microbial flooding test [7-10]. Some scholars observed the migration, adsorption and action mechanism of microorganisms in the model with visual microscopic model [11, 12]. Some results have been obtained in the preliminary experiment on the mechanism and effect evaluation of microbial oil displacement. However, due to the limitation of experimental conditions, the effects of microorganisms in reservoir environment cannot be fully explained. Therefore, nature core, dehydration crude oil and injection water of Baolige oilfield were applied in this paper. First, the performance of microbial flooding system was evaluated in laboratory. Secondly, the experiment of
microbial flooding relative permeability was carried out under reservoir temperature by means of unsteady state method.

2. Experimental materials

2.1. Microbial flooding system
The microbial flooding species were H, z-2 and HB3. The activated medium (LB) included peptone, yeast extract and sodium chloride. The nutrition formula included glucose, urea, ammonium chloride, yeast paste and potassium dihydrogen phosphate.

2.2. Oil and water samples
The viscosity of dehydrated crude oil in Baolige oilfield was 36.606mpa.s at the experimental temperature of 58℃. The viscosity of injected water was 0.495mpa.s at the experimental temperature of 58℃. And the salinity of injected water was 6137mg/l.

2.3. Experimental instruments and cores
The main equipments included 2PB2020 advection pump, Ts-2112b shaker, Ty-3 core gripper, HAAKE MARS viscometer, TX550 interface tensiometer and DGT2006 thermostat. The cores sampling depth of Baolige oilfield was 1504 to 1559 meters. And the core was in the fourth member of the alshan formation of cretaceous.

2.4. Experimental conditions
To simulate the reservoir environment of Baolige oilfield, the experiment adopted constant temperature displacement at 58℃ and constant temperature culture at 58℃.

3. Experimental methods

3.1. Preparation of microbial flooding system
H, Z-2 and HB3 strains were first activated by LB medium. The activated bacterial solution was prepared as microbial flooding bacteria solution in a ratio of 1:1:1. Then, the produced reservoir fluid was used to prepare micro-flooding nutrient solution according to the nutrient formula of 1.1. And the activated bacterial solution was added into the nutrient solution at the concentration of 1.0% to prepare the microbial flooding system.

3.2. Microbial flooding system evaluation experiment
The dehydrate crude oil from Baolige oilfield was added into the microbial flooding system at a ratio of 50g/l. It was placed in a constant temperature shaking table and cultured at 58℃ and 200r/min for 5 days. At the same time, blank samples were made for comparison. The emulsification, viscosity reduction and interfacial tension reduction of crude oil were analyzed.

3.3. Relative permeability experiment

3.3.1. Core preparation
First, the core needed to be washed, dried and polished. Then we measured the length and width of the core and weighed it. Gas permeability experiment was carried out. The differential pressure and gas flow at both ends of the core were recorded. And the permeability of the core was calculated. After 3 to 4 hours of core pumping, the vacuum pump was turned off. And then the core was saturated with formation water. The core wet weight was then weighted and the porosity was calculated. The core parameters were shown in table 1.
Table 1. Core base data

| Core number | Length (cm) | Diameter (cm) | Porosity (%) | Gas permeability (μm²) |
|-------------|-------------|---------------|--------------|------------------------|
| 1# Water flooding | 5.04 | 2.52 | 17.5 | 0.814 |
| 2# Microbial flooding | 5.04 | 2.52 | 17.8 | 0.757 |

3.3.2. Relative permeability test procedure

The relative permeability curve was measured according to the operating procedures of industry standard sy-5354-1999. And the unsteady state method was adopted in this experiment. Experimental procedures were as follows.

- The core was dried and vacuumed to saturate the simulate formation water. The simulated water was produced by formation. The water type was sodium bicarbonate type with a salinity of 6199.2mg/l. The water phase permeability (kw) was measured. The simulated oil was prepared from white oil and dehydrated crude oil produced by Baolige oilfield. The viscosity of simulated oil was 10.5mPa.S at 58°C. Firstly, the core was saturated with simulated oil. The irreducible water was established to be 22.4%. Then the oil phase permeability (ko) was measured.
- The simulate oil was flooded by crude oil at least 2 times of the volume. The core was aged for 2 to 3 days. Then the crude oil permeability (kco) was measured.
- Water flooding experiment was carried out to determine the oil and water phase permeability curve.
- The core was removed, cleaned and send to be washed again. After washing the oil, the core was retested for permeability.
- The core was dried and vacuumed to saturate the simulate formation water. The water phase permeability (kw) was measured. Firstly, the core was saturated with simulated oil. The irreducible water was established to be 21.9%. Then the oil phase permeability (ko) was measured.
- The simulate oil was flooded by crude oil at least 2 times of the volume. The core was aged for 2 days. Then the crude oil permeability (kco) was measured.
- The core saturated with oil was injected into nutrient solution with concentration of 0.81% and bacterial strain with concentration of 1%. After water breakthrough, the injection was stopped and the core was cultured in a constant temperature box at 58°C for 5 days. Then, water flooding was carried out to measure the oil and water phase permeability curve.

4. Results and discussion

4.1. Indoor evaluation results of microbial flooding system

4.1.1. Emulsification effect

The experimental results showed that the flooding system has good emulsifying and dispersing ability. The oil and water could be completely miscible after emulsification. And the emulsification grade was above grade 4. There was no obvious diving line between oil and water, and no stratification after 2 hours standing.

4.1.2. Viscosity reduction effect

The viscosity was determined by MARS viscometer. The results showed that compared with the blank sample, the viscosity reduction effect of the flooding system was good. The viscosity of crude oil decreased from 217mPa.s to 117.83mPa.s. And the viscosity reduction rate was up to 45.7%.

4.1.3. Ability to reduce interfacial tension

The interfacial tension was determined by the interfacial tensionmeter. The interfacial tension of blank sample and microbe was measured. After the action of microbial flooding system, the interfacial tension decreased from 4.32mN/m to 0.92mN/m. And the interfacial tension reduction rate reached...
4.2. Effects of different flooding modes on water content
In the water flooding process, 20.5PV was injected. The flooding time of anhydrous oil recovery period was 70s, and the recovery degree was 8.8%. After water breakthrough, the recovery degree increased by 8.8. The flooding time was 990s when water content reached 100%. The cumulative flooding time was 5013s, and the final recovery degree was 17.6%. In the microbial flooding process, 20.3PV was injected. The flooding time of anhydrous oil recovery period was 346s, and the recovery degree was 11.4%. After water breakthrough, the recovery degree increased by 9.6. The flooding time was 1157s when water content reached 100%. The cumulative flooding time was 2807s, and the final recovery degree was 21%. Microbial flooding process showed obvious longer without water production period, and anhydrous recovery was 2.6% higher than that of water flooding process. And the ultimate recovery increased by 3.4%.

Figure 1. Relationship curve between production degree and injection PV number

4.3. Influence of different flooding modes on recovery degree
The comparison of water content curves between water flooding and microbial flooding showed that both flooding modes had relatively large anhydrous recovery rate as shown in figure 3. After water phase breakthrough, water content of the two flooding modes rose rapidly with similar changing rules, and they all presented a typical s-shape. After the analysis of experimental data, the microbial flooding curve reflected the strong concavity. At the beginning of the flooding, the water cut rise rate of microbial flooding rose slower than water flooding after water breakthrough. In the late stage of microbial flooding, the water cut rose faster than the water flooding. And the microbial flooding was more uniform. The ultimate recovery was 2.4% higher than that of water flooding. It showed that the oil- water interfacial tension was lower in the process of microbial flooding and the oil-water viscosity ratio could be effectively reduced by reducing the crude oil viscosity.

Figure 2. Relationship curve between water content and water saturation

4.4. Effects of different flooding modes on relative permeability curve
The comparison of relative permeability curve between water flooding and microbial flooding was shown in figure 4. As can be seen from the figure, microbial flooding has the following characteristics.
Figure 3. Relative permeability curve

The water phase curve of microbial flooding decreased, and the oil phase curve increased. In the incubator culture process, the microorganisms interacted with the crude oil. And the crude oil viscosity could be effectively reduced by self-degradation and interaction of metabolites such as surfactants. Therefore, at the early stage of flooding, low viscosity oil was easier to be driven out. And the percolation ability of the oil phase increased significantly. With the increase of water saturation, the oil phase gradually changed from continuous phase to non-continuous flow. And the flow resistance of the water phase increased, leading to the decrease of the percolation ability of the oil phase. In the process of flooding, leading to the decrease of the seepage capacity of the water phase. According to the analysis, the first was that the oil-water viscosity ratio decreased due to the decrease of crude oil viscosity. And the oil phase seepage capacity increased, which affected the water phase seepage. Second, with the analysis of the isotonic point, the water-wet degree of the core increased with the progress of microbial flooding, which ultimately leaded to the continuous decrease of the water phase permeability.

The isotonic point of microbial flooding was shifted to the right. The relative permeability value at the isotonic point of microbial flooding and water flooding was basically consistent, which indicated that the two-phase permeability was similar under the two flooding modes. And microbial flooding had little influence on capillary pressure. At the same time, the water saturation at the isotonic point of microbial flooding and water flooding was not significantly different, which was less than 40%. It indicated that the strong oil-wet state of the core has not changed. Although microbial flooding has a tendency to change the core into water wet, but it did not change the wettability of the core.

The two-phase co-permeation zone increased. And the end-point value of oil phase moved to the right. It indicated that the flooding capability of microbial flooding was enhanced. And the residual oil saturation was reduced. Then the final recovery of microbial flooding was improved. On the whole, it was considered that by improving the fluidity ratio of flooding and no flooding phase, microbial flooding could reduce the occurrence of viscous fingering and make the leading edge advance evenly. Thus, the water flood swept volume was increased.

4.5 Flooding pressure analysis of different flooding modes
The flooding pressure under two flooding models was analyzed. When the pressure was stable, the flooding pressure of water flooding fluctuated in 0.72 to 0.78 MPa, and the flooding pressure of microbial flooding changed in the range of 0.44 to 0.55 MPa. The flooding pressure of microbial flooding was obviously smaller than that of water flooding. It was included that the interaction of microorganisms and their metabolites with crude oil reduced the viscosity and interfacial tension of crude oil. Thus, the flow resistance was reduced and the flooding pressure of microbial flooding was reduced.

5. Conclusion
- The interaction of microorganisms and their metabolites with crude oil could effectively reduce the viscosity of crude oil and the interfacial tension between oil and water.
• Compared with water flooding, the relative permeability curve of microbial flooding has the following characteristics. The water phase curve decreased, and the oil phase curve increased. The two-phase co-infiltration zone was enlarged and the end-point value of oil phase was shifted to the right. The isotonic point shifted to the right, but the relative permeability value did not change much.

• The period of anhydrous recovery was longer and the anhydrous recovery was higher of microbial flooding. With the same PV number injected by water flooding, the recovery degree of microbial flooding was higher.

• The flooding pressure of microbial flooding was significantly lower than that of water flooding. The flow resistance of microbial flooding was reduced.

References:
[1] Sun Sangdun. (2014) Field practice and analysis of MEOR in Shengli oilfield. Journal of Oil and Gas Technology, 36(2): 149-152.
[2] Wu Xiaolin, Le Jianjun, Wang Rui. (2013) Progress in pilot tests of microbial enhanced oil recovery in Daqing oilfield. Microbial China, 40(8):1478-1486.
[3] Huang Shiwei, Zhang Yanshan, Huo Jin. (2006) Field experiments on microbial enhanced oil recovery of heavy oil in Xinjiang oil field. Xinjiang Geology, 24(1):84-87.
[4] Li Qing, Wu Gang, Xie Gang. (2011) Research on evaluation of microbe oil recovery bacterium of low-temperature inspissated pool. Oil Drilling & Production Technology, 33(2): 114-116.
[5] Pornsunthornawee O, Attaweepeorn N, Paisanjit S. (2009) Laboratory study on activating indigenous microorganisms to enhance oil recovery in Shengli Oilfield. J Petrol Sci Eng, 66(1):42-46.
[6] Song Z Y, Guo L Y, Qu Y Y. (2008) Microbial surfactant-enhanced mineral oil recovery under laboratory conditions. Colloid Surface B: Biointerf, 63(1): 73-82.
[7] Liu Baolei, Dong Hanping, Yu Li. (2011) Displacement characteristics analysis of bacterial microscopic profile control in reservoir. Journal of Shenzhen University Science and Engineering, 28(4): 356-359.
[8] Yu Li, Wu Guoqing. (2000) The mechanisms study of profile modifying and plugging in porous media for microbe in porous media. Journal of Chongqing University (Natural Science Edition), 23: 142-145.
[9] Yang Peng, Huang Lixin, Yu Li. (2006) Study on the capacity of microbial migration in the low permeability oil reservoir. Petroleum Geology and Recovery Efficiency, 13(2), 85-87.
[10] Han Jianhua, Li Zhanxing, Ju Dengfeng. (2003) The research on physical analog testing for improving microbial oil displacement efficiency. Drilling & Production Technology, 26(6): 86-88.
[11] Ma Jiye, Guo Xingxue, Lei Guanglun. (2008) Microscopic mechanism studies on microbial enhanced oil recovery under high temperature high pressure reservoir conditions. Oilfield Chemistry, 25(4): 369-373.
[12] Saikrishna Maudgalya, Roy M. Knapp, Michael J. Mclnemey. (2007) Microbial Enhanced-Oil-Recovery Technologies: A Review of the Past, Present, and Future. In: 2007 SPE Production and Operations Symposium. Oklahoma City, Oklahoma, U.S.A. SPE 106978.