Research of Microbial-gel Combined Flooding Technology of Ba19 Block in Baolige Oilfield

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Abstract. Ba19 fault block is a medium-high temperature (58°C) reservoir in Baolige Oilfield. The crude oil is characterized by poor physical properties which has high wax and high gum content. The oil-water viscosity ratio is high and this leads to a low water flooding efficiency. The reservoir heterogeneity is high and the contradictions between layers are prominent. According to the characteristics of the oilfield, a microbial-gel combined flooding technology with the microbial flooding as the main body and the gel flooding as the auxiliary is developed to improve the overall development effect of the oilfield water flooding. Microorganism can improve the physical properties of crude oil, and appropriate gel flooding should be carried out to enlarge the sweep volume of microorganism work and improve the effect of microbial-gel combined flooding. By continuous application of this technology in Baolige Oilfield, the concentration of microorganisms is maintained at about 10⁶ a/ml, and the whole microbial field is formed. The average annual reduction rate of crude oil is 48.1%. The microbial-gel combined flooding technology is verified to increase the recovery factor by 9.5%. Since the combined flooding was carried out in 2010, the recoverable reserves of the Ba19 block increased by 630,600 tons.

1. Introduction
MEOR is a comprehensive technology [1, 2]. As early as in 1926, American scientist Beckman puts forward the basic idea of MEOR. Since then, the technology has developed rapidly. Compared with the other flooding method, MEOR technology has the advantages of wide range of application, low cost, simple construction, no pollution to reservoir and water resources, biological environmental protection, and can be used repeatedly[4-6]. There are four ways of MEOR increasing oil recovery, including microbial stimulation, microbial profile control, microbial wax removal and microbial water flooding [7-10]. MEOR is a new enhanced oil recovery technology that utilizes the beneficial activities of microorganisms in the reservoir and their metabolites to act on the residual oil in the reservoir, improves the fluidity of crude oil and increases the permeability of low permeability zone through the effect of the interface properties of crude oil, rock and water. At present, this technology has been widely used all over the word [11-14]. In recent years, the major oilfield in China has also accelerated the pace of MEOR research. Although certain effect was made, but in terms of field application is given priority to with single means, large-scale displacement increased technology application are still less and the effect is not ideal. Therefore, the field application of microbial technology has become a hot spot of MEOR research. In the development process of Baolige Oilfield, there exists the development contradiction of poor oil quality and strong reservoir heterogeneity. Therefore, the authors put forward the microbial-gel combined flooding technology. The microorganism is used to reduce the viscosity of crude oil and improve the fluidity of crude oil. The
gel flooding is used to expand the sweep volume of microorganisms in the formation. Through the field implementation, the problems existing in the process of oilfield development are solved, and the effect of oilfield development has been improved.

2. Test material and method

2.1. Test material
The strains are HB3, IV, Z-2, H, which are isolated from the Ba19 block producing fluid. Nutrients formula system includes the output water 99.36%, molasses 0.2%, glucose 0.2%, urea 0.15%, ammonium chloride 0.05%, yeast extract 0.02%, potassium hydrogen phosphate 0.02%. All the raw materials are fermentation grade. The oil and water samples are mixed crude oil and mixed water produced from Ba19 block. The produced fluid water salinity is 5726 mg/L, and the water type is sodium bicarbonate water type. The ions in the water is Cl-(801.77 mg/L), SO4(11.86 mg/L), Ca2+(3.74 mg/L), Mg2+(3.22 mg/L), HCO3-(3733.23 mg/L), CO32-(83.9 mg/L). Gel formula system includes polymer poly(1800mg/L), polygel ratio(20:1), regulator B(500mg/L). The raw materials are all industrial products, and the gel system is prepared with clear water.

2.2. Formatting author names Test method
① Determination of bacterial count: the dilution coated tablet method[5].
② Emulsion test: 0.74% nutrient solution was prepared with sewage water, 5% oil was added to the oil mixture, and cultured for 36h in a shaker at the constant temperature 45°C of 120r/min.
③ Reduced adhesion test: 0.74% nutrient solution was prepared with sewage water, 40% oil was added to the oil mixture, and cultured for 72h in a shaker at the constant temperature 45°C of 120r/min. The free water in the crude oil was centrifuged at 2000r/min by the centrifuge, and the viscosity of the crude oil after centrifugation was measured by a rotating viscometer at 50°C and 6r/min for 10min.
④ Interfacial tension measurement: the residual oil in the emulsion after the emulsification test was removed, and the interfacial tension of the sample was measured by an interfacial tensiometer at 50°C and 5000r/min for 15min.
⑤ Gelling time determination: at the room temperature, the required raw materials were first mixed into an aqueous solution, and the solution of the regulating and flooding agent was prepared in the grinding bottle according to the test formula, and the sample were put into the oven at constant temperature. The time of gel formation was observed and recorded, and the viscosity of the sample was measured.
⑥ Gel stability measurement: the prepared displacement agent solution was put into the closed container, and the sample was examined at a constant temperature in the thermostat with a specified temperature. Samples were taken at different times, and the viscosity was measured with DV-III+pro rotary viscometer at 6r/min and room temperature.

3. Test results and discussion

3.1. Performance evaluation of microbial formulation system
Using the Ba19 block produced mixed crude oil and produced water, emulsification viscosity reduction test was carried out for four strains of HB3, IV, Z-2, H at reservoir temperature to evaluate the performance of the strains. The evaluation results are shown in Table 1.

| Strains code | Crude oil viscosity | Viscosity ratio | Interfacial tension | Reduced ratio |
|--------------|---------------------|----------------|--------------------|--------------|
| Blank        | 217                 | -              | 4.32               | -            |
| HB3          | 122                 | 43.8           | 1.31               | 69.9         |
Can be seen from the Table 1, 4 kinds of bacteria have good compatibility with the reservoir. And the average viscosity reduction rate of crude oil is 58.3%, and the average interfacial tension reduction rate of microorganism is 79.6%. In order to further increase microbial oil displacement effect, four kinds of species distribution test are carried out. Through the emulsion viscosity reduction test results of the complex strain, the ratio of the complex strain in Ba19 block is finally determined to be 1:1:1:1.

3.2. Performance evaluation of gel formulation system
The formulation system of organic cadmium gel was designed according to the geological characteristics of the oil field. The polymer concentration was 1800mg/L, the polygel ratio was 20:1, and the gelation time was 3h through single factor test. The gelled formulation system was placed in a thermostatic electric heating chamber, and the thermal stability of the gel system was investigated continuously for 35d under reservoir temperature conditions. The results are shown in Figure 1.

It can be seen from Figure 1 that the gel system has good thermal stability, and the viscosity loss rate is only 45% after 35d investigation. The average effective time of water injection of Ba19 block was 35 days, so the selected gel system can meet the requirements of reservoir sealing.

![Figure 1. Thermal stability of gel system](image1)

3.3. The compatibility study of microbial-gel formulation system
In order to be consistent with the field application, the prepared nutrient system was not sterilized, and 1% of the compound bacteria solution was directly inoculated, which was cultured at reservoir temperature for 24h. The bacterial concentration after culture was 1.46×10^8 a/ml. The gelled gel system was added into the prepared formula system according to the volume ratio of 2:1, and the two were evenly mixed and incubated at reservoir temperature. The influence of the gel system on the microbial system was investigated through the change of the concentration, and the test results were shown in Figure 2. Then, the gel system was inoculated with 5% of the above microbial culture solution, and the stability of the gel system was investigated under reservoir temperature. The influence of the microbial system on the gel system was studied through the gel viscosity. The rest results are shown in Figure 3.

![Figure 2. Effect of gel system on microbial system performance](image2)
Can be seen from the Figure 2, microorganism bacteria concentration in examining 35 days are not affected. After culture for 20 days, the concentration of bacteria increased, mainly because the microbial system prepared by using the reservoir produced liquid had more kinds of bacteria, which contained microorganisms that could be grown and propagated by using polyacrylamide. It can be seen from Figure 3 that the gelling performance of the gel system was effect by the microbial system. After 20 days of investigation, the viscosity began to decrease rapidly, and the final viscosity loss rate was 16.3%. Therefore, the microorganism and gel should be inserted in sections during the field implementation of microorganism-gel combined flooding to avoid the influence of direct contact between them and enhance the implementation effect.

4. Application effect analysis of microorganism-gel combined flooding technology

Ba19 block is a medium permeable sandstone reservoir with a burial depth of 500m and a reservoir temperature of 58℃. The ground crude oil wax content is 18.8%, and the gel drain content is 28.7%. The crude oil viscosity is 128.5mPa.s. By using phase injection ways, eight rounds microbial flooding was taken out from 2010 to 2014. Before microbial flooding, key wells were taken the gel flooding to enlarge the sweep volume of microbial working fluid.

Through the application of microbial-gel combined flooding technology, the concentration of bacteria in the produced liquid of Baolige is maintained at more than 10⁶a/ml, and a stable microbial field has been established in the reservoir. The average viscosity reduction rate of crude oil is 48.1% through the action of microorganism, and the physical properties of crude oil are obviously improved. A total of 100×10⁴m³ of working fluid was injected into the microbial-gel combination flooding, which increased the sweep coefficient by 4.6%. According to the standing-point method, the accumulative oil increase was 10.3×10⁴t, and the input-output ratio reached 1:3.2. Through the continuous development of microbial-gel combined flooding technology in Baolige Oilfield, the production and development situation of the oilfield has been significantly improve. According to the statistics of 39 oil wells in Ba19 block, the recovery rate was 17.6% by the water flooding curve calculating. The microbial-gel combined flooding technology was implemented in Baolige Oilfield in 2010. After more than five years of technical development, the calculated recovery rate was 27.1%. Compared with recovery rate before the measures, the recovery rate was increased by 9.5%, and the recoverable reserves increased by 63.96×10⁴t.

5. Conclusion

A) By evaluating the concentration of microbial system and the viscosity of gel system, the compatibility of microbial formula system and gel formula system were studied. According to the influence between the two systems, the piece wise-plug injection of microbial-gel combined flooding was determined.

B) Through the application of microbial-gel combined flooding technology system in Ba19 block, a stable microbial field was established in the reservoir. The average bacterial concentration of the produced liquid was kept above 10⁶a/ml, and the crude oil viscosity was reduced by 48.1% on average.
The physical properties of crude oil were significantly improved, and the sweep coefficient was increased by 4.6%.

C) The application of microbial-gel combined flooding technology in Ba19 block has increased the oil recovery by 9.5% and the recoverable reserves by 63.96×10^4t, indicating that the microbial-gel combined flooding technology has effectively improved the oilfield development effect.

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