Experimental Study on Oil Displacement Mechanism

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Abstract: In this work, the objective is enhancing oil recovery in offshore heavy oil after polymer flooding. The heterogeneous physical model is especially designed for oil fields with heavy oil. The comparative study of the two displacement experiments was carried out, and the experimental data was compared and analysed. The comparison between scheme one and scheme two was analysed from the production curve. The patterns of cores are analysed and compared with each other. It was found that the oil in the high permeability layer and medium permeability layer had been widely removed in the stage of binary combination flooding. There was a high degree of use in the low permeability layer. The recovery ratio is 66.29\%. After polymer flooding, the addition of binary combination flooding in the heavy oil reservoir can greatly enhance oil recovery.

1. Introduction

The production in offshore heavy oil\textsuperscript{[1-2]} field has become an important role in oil production. With difficulty increasing of exploration and the massive need oil in the offshore, it is necessary to invent techniques to greatly enhance the oil recovery in the offshore oil field. With the successful application of chemical flooding in oilfield, chemical flooding having been mature, application of polymer flooding can be used smoothly. This technology gradually expanded to the offshore oilfield. Although there is a high risk to inject agents into the reservoir, binary flooding is usually the first choice after polymer flooding for the offshore oilfield.

Most of the heterogeneous\textsuperscript{[3-4]} thick oil layer in the offshore heavy oil field is in the trail stage of polymer flooding, and the development after polymer flooding has become an urgent need. According to the current need, chemical flooding has been actively used in the offshore heavy oilfield. A number of pilot experiments of polymer flooding\textsuperscript{[7-9]} have been carried out in some experimental blocks, and some achievements have been obtained. At present, there is a lot of research on the recovery ratio of binary flooding\textsuperscript{[5-6]} at home and abroad. However, it is very important to study the binary recovery of offshore oilfields in order to meet the demand of enhancing oil recovery\textsuperscript{[10]} after polymer flooding.

In order to solve the above problems, a three-layer heterogeneous three injection model was developed for the heavy oil M block of offshore. Then, the polymer AP-P5 and the surfactant BH-M2 were used in binary flooding experiment. The effect of enhanced oil recovery on the binary flooding after polymer flooding was analysed by dynamic exploitation curve and the comparison of patterns of core.

2. Experiment

2.1. Experimental conditions
Experimental temperature: 65℃;
Physical model: Three layers of heterogeneous unequal thickness positive rhythm core, core specifications: 300mm×45mm×110mm;
Permeability: 500×10⁻³μm², 2200×10⁻³μm², 4800×10⁻³μm², average permeability: 2500×10⁻³μm²;
The thickness of three layers: 30mm, 30mm, 50mm;
Cylindrical Core Specifications: diameter 25mm, length 100mm;
Saturated water and flooding water: Simulated formation water, salinity 9947.74mg/L;
Experimental oil: viscosity is 70 mPa·s at 65℃;
Binary system: CNOOC provides polymer with molecular mass of 1100×10⁴ AP-P5, surfactant BH-M2. Concentration of polymer solution 1750mg/L, Mass concentration of surfactant 0.2%;
Injection rate: 1 mL/min.

2.2. Experimental scheme

Scheme one: Water flooding to water cut 70%+0.3PV polymer flooding (2000mg/L) + subsequent water flooding to water cut of 95%;
Scheme two: Water flooding to water cut 70%+ 0.3PV polymer flooding (2000mg/L) +0.3PV two flooding (polymer 1750mg/L, surfactant 0.2%) + subsequent water flooding to moisture content of 95%;
Scheme one is used as the comparative experiment. The binary system was supplemented with surfactant BH-M2 600 mg/L·PV after injection of the polymerization amount of 525 mg/L·PV.

| Permeability of core(×10⁻³μm²) | Porosity (%) | Original oil saturation (%) |
|-----------------------------|--------------|-----------------------------|
| 500                         | 25.2         | 68.1                        |
| 2200                        | 30.1         | 72.4                        |
| 4800                        | 34.5         | 78.5                        |

Table 1. Calibrated parameters of each layer

The parameters of calibration core with the same recipe were shown in Table 1. The cores correspond to the three layers of the heterogeneous and unequal thickness physical model used in the typical offshore oilfield block, respectively. The core is used to carry out the saturated oil and exploitation conditions as quantitative comparison.

3. Conclusion and discussion

Table 2. Results of different displacement experiment

| Scheme | Specific scheme | The degree of recovery (%) | Total recovery (%) |
|--------|-----------------|---------------------------|--------------------|
| 1      | Water drive 70% + 0.3PV polymer flooding + follow-up water drive | 16.05 26.47          | 42.52              |
|        | Water drive 70% + 0.3PV polymer flooding | — 26.47          |                    |
| 2      | Water drive 70% + 0.3PV binary flooding + follow-up water drive | 15.59 18.10 31.48  | 66.29              |

According to Table 2:
In scheme one, the total recovery is 42.52%, indicating that 0.3PV polymer can recover 11.52%, after injection of 0.3PV polymer solution.

In scheme two, the total recovery is 66.29% with injection of 0.3PV binary combination solution followed by water drive, after polymer flooding. The experiment indicates that binary system can widely improve recovery ratio after polymer flooding. The binary removed the residual oil which can be removed with polymer viscoelasticity and efficiency of wash oil. Ultra-low interface tension played a key role. Emulsification, decomposition and formation of emulsions made of residual oil back in the flow was caused by ultra-low interface tension. The low interface tension also reduces the capillary force of the residual oil and results in a lower degree of difficulty in the recovery of the residual oil. In the meanwhile, the polymer in the binary solution also exerts the effect of reduction of mobility ratio, so that the residual oil was removed. It can be concluded from the experimental data that the binary flooding is a kind of effective method, especially for the objective development of the sea heavy oil field.

3.1. The analysis of dynamic exploitation curve

There are the characteristic and analysis of dynamic curve of binary flooding after polymer flooding. The measured curve of experiment was shown in the following picture.

![Figure 1. Relation curve between injection PV number and composite water cut, recovery and pressure (water flooding 70%+0.3PV polymer flooding + binary flooding + subsequent water flooding).](image)

It can be seen from Figure 1, in the polymer flooding stage, the composite water cut began to drop to the lowest value, and the pressure rose to the highest value. At this point, the high permeability well produces polymer. In the stage of binary flooding, the composite water cut decreased first and then it increased. The pressure was always rising. At the end of binary flooding, the composite water cut decreased to the lowest value of 15.1%, and the pressure gradually decreases to the lowest value of 0.016MPa, which is 25% higher than the water pressure of 0.012MPa. It indicates that the chemical agent was retained in the core.
When the model is in the binary stage, the comprehensive water cut rate decreases at 0.05PV. After injection of the binary solution, the pressure drop increases continuously, and the binary solution is injected into the range of 0.24PV. The proportion of the absorbing liquid in the high and middle layer does not change obviously. Nearly 22.65% of the total reserves was produced by synergistic effects between the polymer solution viscoelasticity and binary solution. In the binary flooding range of 0.24PV-0.27PV, the pressure difference increased rapidly, the proportion of absorbing liquid by low permeability layer and medium permeability layer significantly increased. Low permeability layer was used, in the injection of binary solution 0.27PV to 0.3PV, the pressure difference gradually decreased, in the meanwhile the wells of high permeability layer will produce binary solution. The composite water cut has dropped significantly to 15.1%. There is some part of binary solution remained in the core. The production of oil accounts for 16.03% of total oil by binary injection of 0.3PV. Overall, in the stage of binary flooding, there is not a great change in absorbing liquid proportion of each layer, but the water cut has dropped significantly. It indicates that the binary solution with a high efficiency of washing oil and can emulsify large area of crude oil. Then the objective of controlling water production will be achieved. The 16.03% of the total oil output in the stage of binary
flooding is less than 18.1% of the polymer flooding stage. The hardship of exploitation in the binary stage is greatly increased. Because the oil produced by the binary solution could not be removed by polymer solution, it indicates that the binary flooding is a kind of effective flooding after polymer flooding in the offshore.

In the stage of subsequent water flooding, the remained binary solution still played a role in absorption liquid decreasing by medium permeability and low permeability layers, composite water cut gradual increasing and pressure descending. The ultimate recovery is 66.29%, subsequent water flooding stage mining 15.44% of the oil.

Because the experimental model with unequal thickness layer, the high permeability layer accounts for 45.5% of the total thickness. The high permeability layer is large, so the contribution of the high permeability layer is the largest in the whole mining process. The high permeability layer and the medium permeability layer are effectively used in polymer flooding stage. The high permeability layer and the medium permeability layer are widely used, and the use of the low permeability layer is also high. It can be seen that the binary flooding effectively mobilizes the residual oil after the polymer flooding.

3.2. Different displacement patterns of core cut

Figure 4. Picture of core cut along the main stream line after flooding (water flooding 70% + 0.3PV polymer flooding + subsequent water flooding)

Figure 4 shows that displacement pattern of core cut after water driving to water cut 70% followed by interjection 0.3 PV polymer solution and subsequent water flooding. The oil saturation of each layer is high, the colour of the high permeability layer is also deeper. Combined with macro-mining data show that there is 57.75% of the reserves in the model has not been mined.

Figure 5. Picture of core cut along the main stream line after binary flooding

Figure 5 is the picture of core after binary flooding. After the binary flooding, the colour of each layer is obviously lighter, the colour of the high permeability layer changes obviously, the colour of medium permeability layer becomes lighter, and the remaining oil in medium permeability layer can be seen. The colour of the low permeability layer is decreased. It indicates that the remaining oil has been removed. Combined with macro-mining data we can see that there is 33.7% of the total reserves of the model has not been mined, indicating that the end of the binary flooding has been 2/3 of the reserves have been mined. The displacement effect of binary flooding is remarkable.
4. Conclusion
The oil recovery can be enhanced significantly by binary flooding after polymer flooding in heavy oil field. The oil produced by the binary solution could not be removed by viscoelasticity and washing efficiency of polymer solution. The binary solution has high washing oil efficiency and quality of emulsifying large area of oil to control water production. In the stage of polymer flooding, the high permeability layer and the medium permeability layer can be effectively mobilized. In the stage of binary flooding, the high permeability layer and the medium permeability layer can be greatly mobilized, and low permeability layer is also a high degree of use.

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