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Physical Simulation of the Displacement Laws for the Binary Compound Flooding in Offshore Oilfields

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Abstract
The researches on EOR effects of the binary compound flooding by means of litho-eletric experimental principles and 3D physical simulation system. The pressure meters and resistivity measuring probe installed on the model can accurately detect the changes of the pressure and saturation fields, and then the production effects of the flooding system are evaluated. The experiments show that for heavy oil binary system, the viscosification of the polymer pre-slug and swept volume enlarging role can be fully played. It can not only drive out the remained oil on the main flow lines, but also displace out the remained oil on both sides of the lines through improving the displacement efficiency. After the binary compound flooding, the remained oil mainly exists on the shunt lines among the producing wells.

Key words: Binary compound/complex/combined flooding; Litho-electric experiment; Saturation field; Oil displaced effect; 3D physical model

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INTRODUCTION
Offshore oilfields are inhomogeneous reservoirs with multi oil layers, natural cores are formed under the complex actions of sedimentary, cementation, compaction and evolution through hundreds of millions of years, and offshore reservoirs are heterogeneous unconsolidated sand reservoirs with high permeability[1-2]. The binary compound flooding technology has become a new direction of tertiary oil recovery technology researches[3], and a large number of studies show that the binary compound flooding can greatly enhance oil recovery[4]. The binary compound flooding is involved with very complex physical and chemical seepage problems, in the past, numerical simulation method, 2D and 3D physical experiments and micro visualization models are used to study the remaining oil distribution of ASP combination flooding and polymer flooding[5-12]. But for the researches on macro seepage laws of binary compound flooding are very few, especially for physics simulation researches on the seepage laws of the binary compound flooding in offshore heavy oil reservoirs. This paper establishes the large three-dimensional physical model for the vertical heterogeneous reservoirs, electrode probes measuring saturation are installed on the physical model, measuring the production effect and saturation field change of the binary compound flooding system, and the effect of enhancing oil recovery and displacement laws of the binary compound flooding are studied.

1. EXPERIMENT DEVICE AND EXPERIMENT METHOD

1.1 Experiment Device

The experiment adopts two sets of advection pumps as the drive system. Measurement system consists of 216 probes measuring saturation, resistivity collector and a PC computer. The minimum flow rate of advection pumps is 0.01 mL/min, the measurement range of 216 probes measuring saturation is from 0 to 50 MΩ·m, and measuring accuracy is 10 MΩ·m.

Three-dimensional physical model with positive rhythm and longitudinal heterogeneity is used in the experiment, and the model size is 60 cm × 60 cm × 4.5 cm. The permeability of three layers is respectively 0.5, 0.5, 3.5 μm^2, the experiment simulates the five-point well pattern with a injection well and four production wells, and the injection well and four production wells are drilled into vertical wells, the well length is 3.75 cm, and the diameter is 0.2 cm; 54 measurement points and 216 probes measuring saturation are uniformly laid out on the model, and the diameter of the probes is 0.2 mm, as shown in Figure 1.

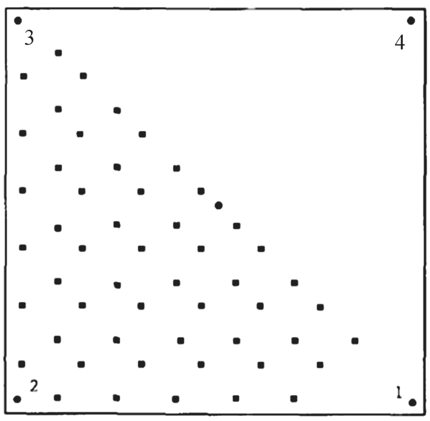

Figure 1
Planar Map of 3D Heterogeneous Non-Interlayer Physical Model

1.2 Method of Measurement Saturation

In the experiment, the relation curve between resistivity and saturation is drawn, in order to make the cores form different oil saturations, crude oil and another solution are injected according to the proportion of different injection speeds in the experiment, making oil saturation of the cores change gradually, and then corresponding resistivity of different saturations is got, as shown in Figure 2.

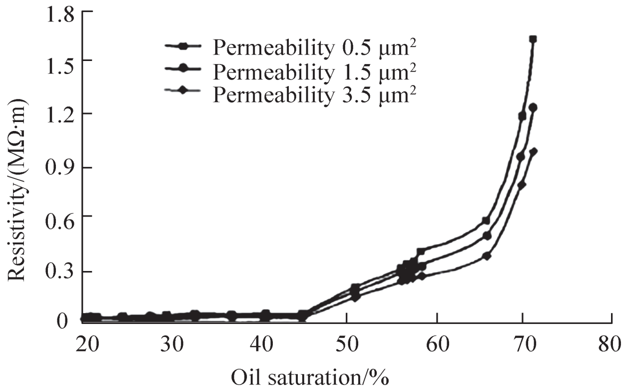

Figure 2
Relations Between the Resistance and Oi1 Saturation

2. ANALYSIS OF EXPERIMENT RESULTS

2.1 Production Effect

It can be seen that from Figure 3, after water flooding, with the polymer injection, integrated water cut of production wells is on the decline. At the stage of the injected binary compound slug, the overall water cut of the model significantly decreases, from 79.65% at the end of the water drive to a minimum of 31.52%, and the oil recovery degree has increased significantly. The final recovery degree increases by 41.63%.

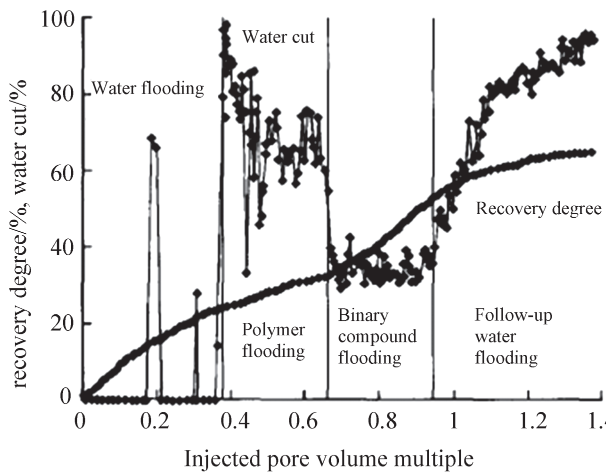

Figure 3
Changed Relations Between the Recovery Degree and Water Cut

2.2 Pressure Change

According to Darcy's law and the distribution laws of flow field and potential field, pressure change is the dynamic reflect of reservoir fluid flow, by means of pressure change of injection well and each point on the mainstream line, the degree of expanding the swept volume of the binary compound flooding is analyzed, and displacement law of the binary compound flooding is studied[13].

From the curves of pressure change of the injection well and 3 mainstream lines in the experimental model, it can be seen that, at the stage of polymer injection, injection pressure keeps increasing continuously, this is because the injected polymer slug is smaller, polymer flooding in the model has not been over. At the stage of the injected binary compound slug, the pressure continues to rise, after that, pressure falls quickly and finally keeps stable, this is because the reinforced adhesion, retention of the previous polymer slug causes the flow resistance increase, making the early injection pressure of binary compound slug increase, as shown in Figure 4.

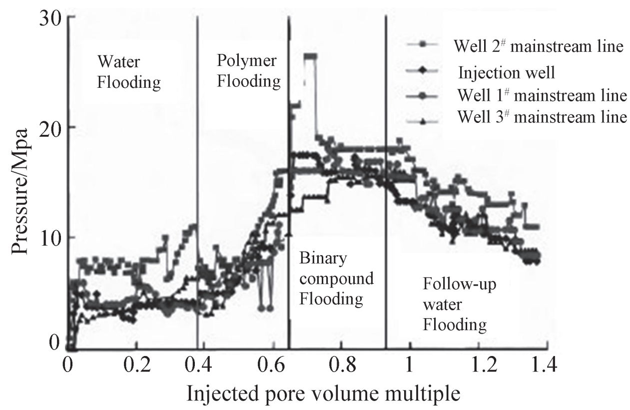

Figure 4
Changes of Each Pressure Testing Point for the Model

After transferring into subsequent water flooding stage, injection pressure slowly declines, and finally stable pressure is higher than the pressure of water drive, this is because the chemicals improve the action such as mobility ratio, enlarging resistance coefficient and residual resistance coefficient[14]. Figure 4 shows binary compound and polymer flooding improve the overall pressure of the model. During the stage of binary compound injection, pressure differential between the pressure on the three mainstream lines and injection pressure increases, this is because enlarging swept volume of binary compound flooding makes the binary solution sweep to both sides of the mainstream lines, and then differential pressure on the mainstream lines increases.

2.3 Oil Saturation Change

The electrode affects the seepage in the process of displacement in the model, the influence in experiments is processed and corrected, and oil saturation distribution of each displacement stage is obtained finally.

After water flooding ends, swept degree along different directions in the mainstream lines is not the same, residual oil after water flooding is mainly formed by the the heterogeneity of microscopic pore and the capillary pressure, it can be seen from Figure 5, when water cut for water flooding in the model reaches 70%, the water flooding in the model doesn't end, due to the heterogeneity of the micro pore, the affected degree in the deriction of 3 production wells is different, a large number of remaining oil exists on the both sides of mainstream channels between injector well and producer wells, while oil saturation is higher among the production wells in the edge of the model, there is a lot of remaining oil, and the oil saturation in the model is about 50%.

It can be seen from Figure 6 that on the mainstream channels between injector-producer wells, oil saturation reduces dramatically after polymer slug is injected, by a drop of about 16%, this is because the viscoelastic characteristic of the polymer overcome the capillary force in whole or in part, thus the remaining oil is pulled out, besides, as a result of the action of polymer expanding swept volume, the swept volume is expanded by about 20%, the oil wall forms on both sides of the mainstream lines, regional oil saturation reduces, and then the remaining oil mainly exist on the shunt lines between the production wells near the edge area of the model, the area is not affected; formation position of remaining oil is related to affected degree of polymer in the deriction of production wells, in the different directions the better affected effect, the smaller residual oil area, and close to the production wells.

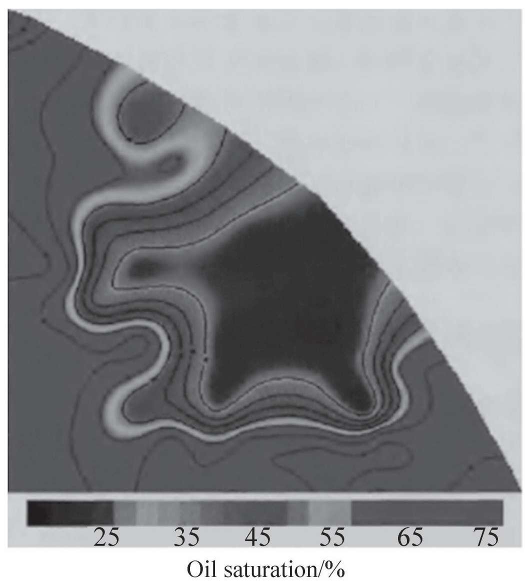

Figure 5
Oil Saturation Distributions at the End of the Water Flooding

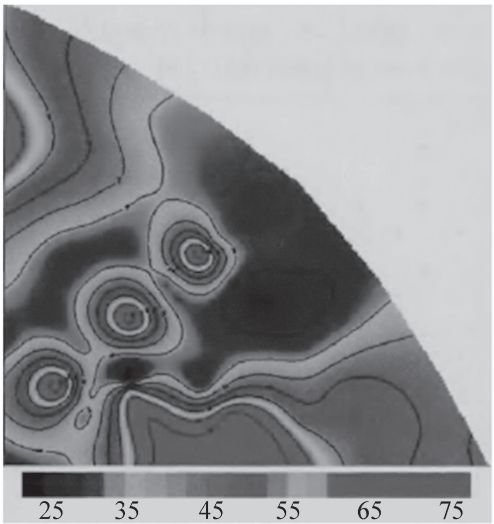

Figure 6
Oil Saturation Distributions at the End of Polymer Flooding

With binary displacement solution injection, the increase of the swept volume in the model is not obvious, increase by about 7% compared with the swept volume after injected polymer slug. From Figure 7, it can be seen that as the injection pressure of binary compound keeps stale, the effect of expanding swept volume tends to be stable, at the same time, the oil saturation within the affected area reduces greatly, displacement effect on the shunt lines is remarkable, a part of remaining oil after the polymer flooding (mainly distributes on the shunt lines between production wells) is displaced out, and oil saturation reduces by about 15%. The residual oil in the model is less and less, this is because the effect of reducing interfacial tension of binary displacement solution is superior to that of polymer solution, making remaining oil within the area affected by the polymer flooding flow again, and be carried out, as shown in Figure 8.

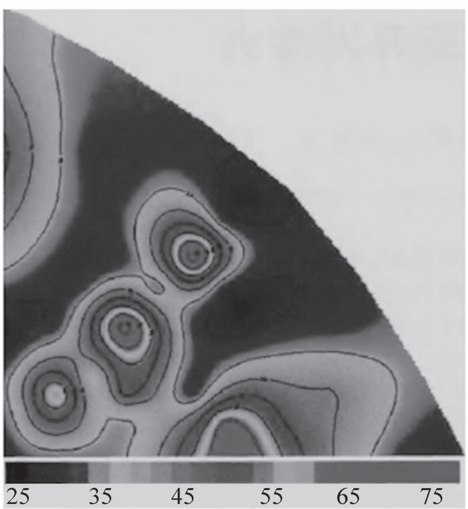

Figure 7
Oil Saturation Distributions at the End of Binary Flooding

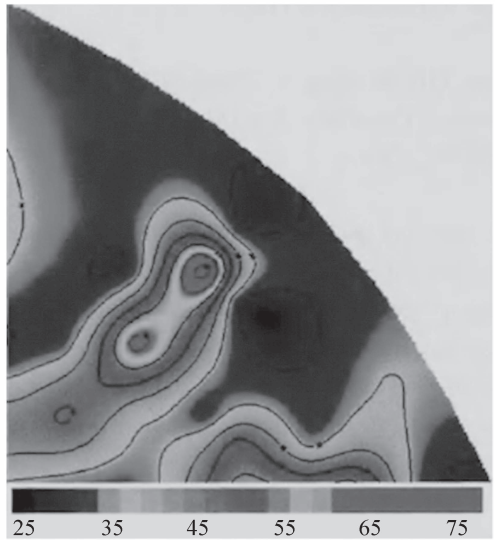

Figure 8
Oil Saturation Distributions at the End of Follow-up Water Flooding

By comparing with saturation distribution between polymer flooding and binary flooding, it can be seen that after the early injected polymer slug, the pressure doesn't keep stable, that is the polymer displacement is not over, at the beginning of the binary compund injection, due to the influence of the early injected polymer and expanding swept volume of binary flooding itself, the injection pressure increases, the plane swept volume in the model (on both sides of the mainstream lines) continues to increase, the remaining oil in which will be displaced out.

CONCLUSION

For 3D physical model of offshore oilfield, in the displacement scheme, for injected polymer of 0.3 PV, the action of the polymer in the reservoir is mainly adsorption, retention etc, which makes flow resistance increase, reservoir pressure rise, adjusts injection profile, and then make the pressure of the model increase and expand the swept volume, displace out remaining oil in the residual oil zone on the both sides of the mainstream lines and improve macro swept volume.

Under the synergy of binary complex system, due to the action of polymer and binary solution itself, by continuing to improve the swept volume, binary compound displacement fluid displaces out remaining oil of the remaining oil area on the on both sides of the mainstream lines, and due to super displacement efficiency of the binary composite system, part of remaining oil on the shunt lines between production wells and irreducible oil in the area affected by polymer are displaced out, the overall oil recovery in the model is improved.

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