Technical Analysis of Enhanced Oil Recovery by Polymer Flooding

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Abstract. Polymer flooding is one of the effective technologies to improve oil recovery. This paper briefly introduces the mechanism of polymer flooding, and describes the application advantages of polymer flooding in heavy oil sandstone reservoirs in China. Combined with the application practice of polymer flooding EOR technology, the scheme of polymer flooding EOR technology is further explored from the aspects of polymer flooding oil supply, polymer flooding oil injection mode and polymer solution mass concentration, hoping to provide some references for the improvement of reservoir recovery.

Keywords: Polymer flooding, recovery factor, high-viscosity crude oil.

1. Introduction

In 1950s, China began to study EOR technology of tertiary oil recovery, and polymer flooding began to be applied in heavy oil sandstone reservoir exploitation. In 1965, China conducted experiments in the shallow layer of Heiyoushan, Karamay Oilfield, Xinjiang oil province, and determined that polymer flooding could increase the recovery of heavy oil sandstone reservoir by 8.6%.Then, polymer flooding technology has been implemented in Daqing oil area, Shengli oil area, Liaohe oil area and Jianghan oil field, and good results have been achieved. Therefore, the analysis of polymer flooding EOR technology has very prominent practical significance.

2. Mechanism of polymer flooding

Polymer flooding can also be called modified water flooding (secondary oil recovery). As shown in Figure 1, polymer flooding can inject high-viscosity polymer through polymer injection wells, increase the viscosity of injected water, promote the improvement of water-oil mobility ratio, and expand the wave and volume of injected water in oil layer, which can promote the improvement of crude oil recovery. Especially in the oil layer where the injected water wave reaches, the residual oil is retained in the pore medium, near the rock surface and "blind end" in the form of film, column, cluster, island and blind. The viscoelastic polymer solution with a certain mass concentration is injected at the same speed. The velocity gradient of the polymer solution near the rock surface is greater than that of water and high viscosity, It can produce a "drag force" parallel to the oil-water interface and acting on the residual oil on the pore and rock surface, which can effectively drive and replace the residual oil. At the same time, the elastic viscous polymer can not only expand as the blind end of the pore expands, but also shrink as the blind end of the pore shrinks during the "piston flow" process. Then the high-speed and high-viscosity edge position of the stream is used to drive, replace, and "drag". The “blind-end” residual oil saturation is reduced, and the effect of improving the oil recovery factor of the reservoir [1].

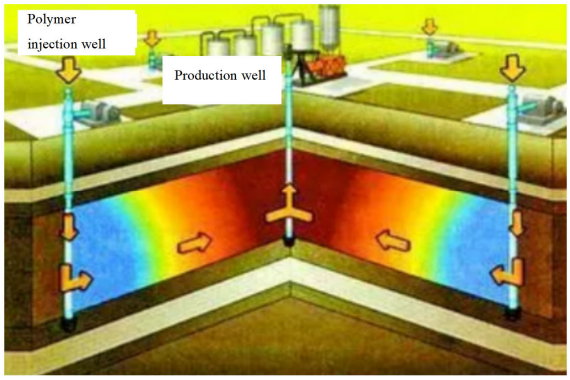

Fig. 1 Polymer flooding

3. Application advantages of polymer flooding in heavy oil sandstone reservoirs in China

3.1 Suitable for heterogeneous reservoirs.

In China, most oil field reservoirs are continental sediments with significant heterogeneity, and the permeability variation coefficient is more than 0.5.High-

viscosity crude oil has a faster rate of water cut during the development process. Even if the injection and production system of enhanced oil recovery is used, it cannot ensure that the waterflooding recovery rate meets the target requirements. However, the use of polymer flooding can ensure the smooth achievement of the recovery target.

3.2 In the optimum viscosity range

Some reservoirs in China are high-viscosity crude oil, with the lowest viscosity of 5.0MPa·s and the highest viscosity of 50MPa·s, which is the best viscosity range for polymer flooding.At the same time, before the formation temperature of the oil field where the high viscosity crude oil is located is 45.0 ℃ ~ 70.0 ℃, the polymer fusion will not undergo chemical degradation, and the requirements for deoxidation of injected water are not high.The research and application of polymers suitable for formation water with high salinity also provides sufficient support for polymer flooding of China's high-viscosity crude oil.

3.3 Great potential

From the analysis of the types of oil fields developed in China, it can be seen that the heavy oil sandstone reservoir accounts for a high proportion in the developed oil fields in China, and the thermal recovery production of heavy oil is the primary task of EOR.In the thermal recovery of heavy oil, the reserves of onshore oilfields suitable for polymer flooding have reached 43.6×1011kg, with great potential.Especially for the positive rhythmic sedimentary reservoir of fluvial facies reservoir, polymer flooding can be used to recover the remaining oil in the "blind area" in the upper part of the reservoir after the adjustment of water injection profile.

3.4 Little salt sensitivity effect

In eastern China, the salinity of formation water in main oil fields is between 3000.00mg/l and 7000.00mg/l, and the overall degree is not high. When the polymer solution encounters formation water with low salinity, the salt-sensitivity effect is in the lower category and will not cause the viscosity of the crude oil to drop significantly, and the polymer flooding has a better effect of enhancing the recovery factor.

4. Technical scheme of enhanced oil recovery by polymer flooding

4.1 Polymer source

Natural polymers and synthetic polymers are the main types of polymers for mobility control at present. The former is mainly used in reservoirs with high salinity and high shear force, such as biopolymer xanthan gum. The latter is applied to a large number of oil reservoirs, such as hydrolyzed polyacrylamide and polyacrylamide [2]. General high molecular weight polyacrylamide is suitable for high viscosity crude oil reservoir; Low molecular weight and high mobility polymer (polyacrylamide) is suitable for low permeability sandy reservoir; Salt resistant polymer (polyacrylamide) is suitable for reservoirs with high water salinity.

4.2 Injection timing

The timing of injection is a key factor that affects the effect of polymer flooding to increase oil recovery. Starting from the period of ordinary polymer flooding to high-quality concentration polymer flooding, the polymer injection period can be divided into early, middle, middle, middle, late, Later period [3]. In the early stage, high-quality polymer flooding was directly injected after the end of water flooding.In the middle and early stage, the water cut of ordinary polymer flooding dropped to about 80.0% for the first time, and high-concentration polymer flooding was used. In the middle stage, high concentration polymer flooding is mainly transferred when the water content of ordinary polymer flooding reaches the lowest point. In the middle and late stages, the injection of high-concentration polymer flooding is mainly when the water content of ordinary polymer flooding rises to about 80.0% again. In the later stage, the injection of high-concentration polymer flooding is mainly when the water cut of ordinary polymer flooding rises to about 98.0%. Generally inject in advance, it can promote the increase of movable oil in the core and formation, and the decrease of residual oil in the "blind end" shape of the hydrophilic rock, which improves the recovery factor.Therefore, when the mass concentration of polymer flooding is between 2000 mg/L and 2500 mg/L, we should try our best to inject polymer solution in the early, middle and early stages.

4.3 Injection method

Only by ensuring that the increase of polymer mass concentration and molecular weight exceeds the injection pressure can we ensure that the current injection rate and injection production system of the oilfield are in equilibrium. Under the premise that the injection pressure is lower than the formation fracture pressure, technicians need to determine the best high-quality concentration polymer injection method from several aspects such as polymer molecular weight, injection speed, and mass concentration.

Firstly, the oil displacement effects of polymers with molecular weights of 1500×104, 1800×104 and 2100×104 were analyzed. Because the polymer with high relative molecular weight has stronger viscoelasticity, it can expand the swept volume of the polymer and improve the oil displacement efficiency of the polymer. The oil displacement effect of the polymer with high relative molecular weight is better than that of the polymer with low relative molecular weight. However, when the relative molecular weight of the polymer reaches about 1800×104, the rate of increase in the recovery factor returns to a stable level. Therefore, a polymer flooding with a molecular weight of 1800×104 can be selected.

Secondly, the relationship between the mass concentration of polymer solution and oil recovery is analyzed when the molecular weight (1800×104) is constant. Choose the artificial homogeneous core column of φ2.5cm×10cm and the heterogeneous core column of

4.5cm×4.5cm×30.0cm (coefficient of variation 0.65)[4].The simulated oil is a mixture of crude oil and kerosene in the oil production plant. Its viscosity is 9.76MPa·s~9.89MPa·s at 45.0℃. The water is selected as artificial synthetic brine with a salinity of 6778.22mg/L, and the core flooding water is selected for mine Synthetic salt water with a degree of 3700.21 mg/L, and synthetic water with a degree of salinity of 607.89 mg/L for the polymer water.Under the condition of 45.0℃, a polymer slug with a size of 0.57pv was injected. For an artificial homogeneous core column with a molecular weight of 13.0×10^{-6}, polymer solutions with mass concentrations of 1000mg/L, 1500mg/L, and 2000mg/L are injected respectively. The corresponding air permeability is $940\times10^{-3}\,\mu m^2$, $945\times10^{-3}\,\mu m^2$, $935\times10^{-3}\,\mu m^2$ .The oil saturation is 70.69%, 66.35% and 71.25% respectively. Water drive recovery is 41.23%, 40.23% and 38.65% respectively. The recovery rates of polymer flooding are 11.32%, 14.32%, and 40.32%, respectively. The pressure difference is 1.89MPa, 3.65MPa and 4.13MPa respectively. For molecular weight 17.0×10^{-6} artificial heterogeneous core column, inject polymer solutions with mass concentrations of 1000mg / L, 1500mg / L and 2000mg / L respectively. The corresponding air permeability is $1036\times10^{-3}\,\mu m^2$, $1025\times10^{-3}\,\mu m^2$, $1052\times10^{-3}\,\mu m^2$ .The oil saturation is 70.84%, 70.94% and 70.75%, the water flooding recovery is 39.4%, 39.4% and 39.8%, the polymer flooding recovery is 18.32%, 24.32% and 26.38%, and the pressure difference is 1.00MPa, 1.31MPa and 1.78 respectively.

It can be seen from the above data that when the molecular weight is the same, as the mass concentration of the polymer solution develops to a high level, the oil recovery rate also develops to a high level, and the injection pressure develops toward a high level, and the recovery rate of a high concentration polymer It is close to the level of ASP flooding. Therefore, a high concentration polymer with a mass concentration of about 2000mg/L can be selected. At the same time, starting with the control of injection pressure difference at both ends of the core, the injection speed is controlled below 6mL/h to realize low-pressure injection [5]. Specifically, when the core is saturated with oil and the water cut of water flooding reaches 98.0%, technicians can use polymer flooding until the pressure reaches the equilibrium level.Furthermore, a 5% chlorine dioxide solution with a pore volume of 1pv is used to remove the polymer molecular film (containing polymer molecules adsorbed on the surface of the pores) on the rock surface to complete the deblocking.After removing the plugging, inject a 0.6% NOS surfactant solution with a pore volume of 1 pv or a 1.0% NOS surfactant fusion + 1.0% additive surfactant system, and continue to inject the polymer solution.By injecting low interfacial tension water containing active agent into pores, the interfacial tension between water and oil can be reduced to a lower level, which provides a basis for improving the relative permeability of polymer solution, thus achieving the purpose of reducing the injection pressure difference.

4.4 Slug and injection method

When the relative molecular weight and mass concentration of polymer are certain, polymer slug has a great influence on polymer flooding effect. At this time, it is very important to select the appropriate polymer slug from the perspective of maximizing profit [6]. Generally, when the polymer slug increases, the effect of polymer flooding to increase oil recovery will be improved, but after the polymer flooding slug increases to a certain value, the rate of increase in oil recovery will gradually decrease and eventually approach zero. At the same time, considering the price of polymer slug and the cost of chemical agent per ton of oil, 0.70pv to 1.00pv slug can be preferred.

After the slug is determined, in order to maximize the advantages of polymer slug, the "stepped" slug injection scheme can be selected. That is, the mass concentration of the main slug accounting for a large proportion of the dosage shall exceed the overall slug mass concentration optimized under the same dosage. At the same time, on the premise of ensuring the slug spreading ability, the "stepped" slug is used to carry out fluidity maintenance to avoid the problem of sudden entry of subsequent injected water [7]. The whole slug is 2000mg/L×0.808pv, the main slug in the "stepped" slug is 2000mg/L×0.748pv, the secondary slug 1 and the secondary slug 2 are 1000mg/L×0.100pv, 500mg/ L×0.100pv. In the process of alternating injection of "stepped" slug from high to low, the balance of residual oil will be affected by the change of driving force. At high mass concentration, the slug driving power will be higher, otherwise it will be lower, which can destroy the balance state of residual oil, promote it to enter the area where the polymer solution has been displaced, and then be "taken away" by the high mass concentration polymer solution flowing through again.

5. Summary

In summary, whether it is a homogeneous core or a heterogeneous core, polymer flooding has a significant effect of enhancing oil recovery. It can not only promote the decrease of the oil-water viscosity ratio, but also increase the thickness of the layer water absorption, the macroscopic sweep efficiency of water flooding, and ultimately increase the oil recovery. The mass concentration and injection speed of polymer solution have great influence on oil displacement recovery. In order to improve the oil displacement recovery ratio, we can control the injection speed while increasing the mass concentration of polymer solution, and add low tension surfactant system appropriately. Combined with reasonable selection of polymer slug and alternate injection, the effective permeability of polymer solution is at a high level.

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