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 °C ~ 70.0 °C, 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
cut 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
difference is 1.89MPa, 3.65MPa and 4.13MPa respectively. The pressure recovery rates of polymer flooding are 11.32%, 14.32%, and 40.32%, respectively. The recovery rates of polymer flooding are 70.69%, 66.35% and 71.25% respectively.

The corresponding air permeability is $940 \times 10^{-3} \, \mu \text{m}^2$, $945 \times 10^{-3} \, \mu \text{m}^2$, $935 \times 10^{-3} \, \mu \text{m}^2$. 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 $17.0 \times 10^{-6}$ artificial heterogeneous core column, inject polymer solutions with mass concentrations of 1000mg/L, 1500mg/L, and 2000mg/L are injected respectively. The corresponding air permeability is $1036 \times 10^{-3} \, \mu \text{m}^2$, $1025 \times 10^{-3} \, \mu \text{m}^2$, $1052 \times 10^{-3} \, \mu \text{m}^2$. 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 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 is at a high level.

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 homogenous 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.
References


