Experimental evaluation of polymer performance for tertiary oil recovery in oil field

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Abstract. Polymer flooding is an important technology for enhancing the recovery of underground crude oil, and it is currently the most widely used technology for enhancing recovery in China. The main principle of polymer flooding is to increase the viscosity of injected water through a water-soluble polymer, thereby improving the mobility ratio, expanding the swept volume, and increasing the oil recovery rate and crude oil recovery factor. The viscosity-increasing performance of the polymer solution is the most important parameter of its oil displacement characteristics. The main factors that affect the viscosity of the polymer are the molecular structure, molecular weight, concentration, the salinity of formation water or injected water, temperature, and formation shear. Therefore, the viscosity-increasing performance, salt resistance, and shear resistance of the polymer are evaluated. Through indoor experiments under target reservoir conditions, the viscosity-concentration curves of four polymers A, B, C, and D are measured, and the viscosity data before and after shearing of the polymer as well as the viscosity of the polymer at different salinities are obtained. The results show that, considering the viscosity-increasing performance, shear resistance, salt resistance and quality control of the polymer, under the experimental conditions, the recommended sequence of the 4 polymers is: A, C, D, and B.

1. Introduction
Polymer flooding is a very important technology to improve oil recovery, and it plays a very important role in oilfield development, especially in the development of old oilfields. In the research and application of polymer flooding to improve oil recovery, viscosity is the core index to characterize the performance of polymer solution [1]. The important performance parameters of polymers—salt resistance and shear resistance—are all characterized by viscosity and viscosity retention. Measuring the viscosity of the polymer solution with a viscometer and then evaluating the performance of the polymer is a common practice in polymer flooding laboratory experiments and field applications in oil fields. By dissolving the water-soluble polymer polyacrylamide (HPAM) into the injection water and then injecting it into the formation, it not only supplements formation energy, but also improves the oil displacement effect [2]. After nearly 50 years of research, the basic principle of polymer flooding has now been clarified, that is, by increasing the viscosity of the injection system (for example, the viscosity of water is increased from 0.6mPa.s to 30-300mPa.s), thereby greatly expanding the injection swept volume of water (solution), thereby improving oil recovery.

The viscoelasticity of polymers also contributes positively to the enhanced oil recovery, although this issue remains controversial. Although polymer flooding is not proposed first in China, the application scale of polymer flooding in China far exceed those abroad [3]. PetroChina Daqing Oilfield
began to industrialize polymer flooding technology in 1996, Sinopec Shengli Oilfield industrialized the application of polymer flooding in 1997, and China National Offshore Oil Corporation launched the world’s first offshore oilfield injection enhanced oil recovery in Bohai in 2003. In the field test of recovery rate, polymer flooding has become the leading technology for stable production and enhanced oil recovery in domestic oilfields. Due to its large scale and wide application, domestic polymer flooding technology for enhanced oil recovery is ahead of foreign countries [4].

The basic principle of enhanced oil recovery is to expand sweep efficiency and increase oil displacement efficiency. The oil displacement efficiency is affected by the number of capillary tubes, and the contribution of polymers to the oil displacement efficiency is very limited, mainly to expand the sweep efficiency or sweep volume [5]. The basic principle of polymer flooding to enhance oil recovery is to increase the viscosity of injected water and reduce the mobility ratio of the displacement phase (water) and the displaced phase (oil), thereby reducing the "finger-in" viscosity and expanding the swept volume. Figure 1 is a schematic diagram of water flooding and polymer flooding. Obviously, compared with polymer flooding, water flooding is easier to "finger", resulting in a decrease in the proportion of affected oil (sweeping efficiency). Figure 2 reflects the influence of mobility ratio on the affected system. The abscissa is the mobility ratio, and the ordinate is the vertical sweep efficiency (ratio of the swept volume to the total volume) at the time of breakthrough (water breakthrough in the oil production well). The larger the degree ratio, the smaller the affected volume. The figure also shows that when the mobility is less than 1, the swept volume is significantly higher than the swept volume when the mobility ratio is greater than 1. The range of mobility ratio under reservoir conditions is generally 0.5-50. For water flooding oil, since the viscosity of oil is not easy to change (except for heavy oil thermal recovery), and the relative permeability ratio has a very small range, increasing the water phase viscosity can reduce the mobility ratio. Therefore, the viscosity of the polymer is the most important displacement parameter.

Figure 1. Schematic diagram of water flooding and polymer flooding.
In the experiment, the performance of polymer flooding, the viscosity-increasing performance, salt resistance and shear resistance of polymers with a given molecular weight are generally investigated. Tackifying performance is to examine the viscosity-concentration curve of a given molecular weight polymer. Salt resistance is to investigate the influence of salinity on polymer viscosity. The shear performance is to investigate the shear resistance of polymers, especially the change in viscosity after blasthole shearing. The indoor experiments usually uses Wu Yin blender or soybean milk machine to simulate high-speed blasthole shear. A commonly used Wu Yin blender is shown in Figure 3. The viscosity of the polymer is generally measured with a rotary viscometer. Although there are different viscometers, the most commonly used viscometer in the petroleum industry is the Brookfield viscometer, also known as the Brookfield viscometer.

2. Experimental materials and methods

2.1 Experimental conditions

2.1.1. Polymer
The polymers A, B, C, D provided by an oilfield company are powdery and white. The effective content is 88%-90%, the degree of hydrolysis is 22%-24%, and the molecular weight is 15 million and 22 million. Its physical and chemical properties meet the requirements of the national standard "SYT5862-2008 Technical Requirements for Flooding Polymers" for partially hydrolyzed polyacrylamide for flooding. For polymer screening, this experiment only selects 4 types of polymers to develop a software for evaluating the main performance of oil displacement polymers.
2.1.2. Experimental water
The simulated water is configured according to the formation water of the target oilfield block, and the water quality composition is shown in Table 1. For the salt tolerance evaluation test, the total mineralization is 150%.

2.1.3. Test equipment
The main experimental instrument includes Brookfield viscometer, the overhead stirrer, the water bath tank and Wu Yin agitator.

Table 1. Test water quality composition.

| Ion         | K⁺ | Na⁺ | Ca²⁺+Mg²⁺ | Cl⁻ | HCO₃⁻ | CO₃²⁻ | SO₄²⁻ | Salinity |
|-------------|----|-----|-----------|-----|-------|-------|-------|---------|
| Concentration, ppm | 140 | 2300 | 40        | 190 | 5500  | 200   | 120   | 8490    |

2.2 Experimental method

2.2.1. Determine the viscosity curve
The main technical points include preparing a polymer mother liquor with a concentration of 5000ppm, stirring with a stirrer for 4 hours, accurately weighing the polymer, and slowly pouring the polymer powder into the polymer dissolution process. After the polymer mother liquor is stirred, it needs to stand for more than 24 hours, and then the target solution of different concentration is prepared. The target solution concentration includes 500ppm, 1000ppm, 1500ppm, 2000ppm, 2500ppm, respectively. The target solution is configured according to the amount of experiment, but it should not be too much, avoiding stirring unevenly. The viscosity can be measured with a viscometer after configuring the target liquid.

When measuring the viscosity, if the viscosity is less than 100cP, we select the zero rotor with a speed of 6r/min, and the corresponding shear rate is 7.34 1/s. When the viscosity is greater than 100cP, we select the No. 1 rotor with a speed of 6r/min, corresponding to the shear rate of 7.34 1/s. The viscosity measurement temperature is 75°C which is same as the target reservoir temperature. The high salinity in this study is a relative concept, which is different from the high mineralization of oil reservoirs in the field of enhanced oil recovery. A key issue in the evaluation of salt tolerance is how to choose the polymer concentration. One approach is to use the target block concentration. Therefore, the polymer concentration used in the mine field test is investigated. In the early days, it was mostly 1000ppm, and now it is 1500ppm. The target concentration of the target reservoir block is 1500 ppm, so the concentration of 1500 ppm is adopted. However, since the polymer may not progress in a slug in the formation as expected, the salt tolerance evaluation is based on a target concentration of 1500 ppm.

2.2.2. Shearing experiment
The main purpose of the shear test is to evaluate the viscosity loss of the polymer after high-speed shear. The shear experiment method is to use Wu Yin agitator to evaluate the shear resistance of the polymer by controlling the gear position and shear time. The viscosity retention rate is evaluated by measuring the viscosity before and after shearing. Shear experiments need to choose a suitable polymer concentration. In this experiment, the shear resistance of the polymer at multiple concentrations is investigated. Since the polymer is sheared, a large amount of foam will be produced. Therefore, when measuring the viscosity of the polymer after shearing, it is necessary to wait for the foam to be completely eliminated. Generally, it needs to stand still for 12-24 hours. If necessary, measures such as water bath must be taken to accelerate the defoaming.

3. Results and analysis

3.1 Tackifying performance
Table 2 is the viscosity concentration curve of 4 kinds of polymers. From the results of the viscosity test, the viscosity of the polymer is closely related to the concentration. The greater the concentration, the higher the viscosity. Under the concentration of 500 ppm, polymer A has the highest viscosity and polymer B has the lowest viscosity. Under the concentration of 1000 ppm, polymer C has the highest viscosity and polymer B has the lowest viscosity. Under the concentration of 1500 ppm, polymer C has the highest viscosity and polymer A has the lowest viscosity. Under the concentration of 2000 ppm concentration, the relative order of the polymer viscosity is: C > B > D > A. Under the concentration of 2500 ppm, the relationship between the polymer viscosity is: C > B > D > A. In other words, if the concentration of 1500 ppm is used as a reference, polymer A and D have the same viscosity, polymer C has the highest viscosity, and polymer B takes the second place. If we choose one polymer, we should choose polymer C; if we choose two polymers, you should choose polymers B and C.

Table 2. Viscosity results.

| Concentration, ppm | A  | B  | C  | D  |
|-------------------|----|----|----|----|
| 500               | 5.24| 2.24| 4.25| 3.19|
| 1000              | 19.22| 13.66| 33.11| 17.56|
| 1500              | 41.36| 48.14| 86.38| 41.73|
| 2000              | 75.43| 155.56| 195.14| 88.42|
| 2500              | 124.58| 197.33| 307.29| 137.35|

The viscosity of polymer C is much higher than that of the other three polymers, and the viscosity-concentration curve of polymer B is significantly different from that of the other three polymers. The viscosity-concentration curves of polymers A and D are relatively close. At different concentrations, the difference between the viscosities of the four polymerizations is different. When the concentration is 1500 ppm, the viscosity difference between polymer C and the other three polymers is obvious. When the concentration is 2000 ppm and 2500 ppm, the viscosity difference between polymer B and C and other polymers is obvious.

3.2. Salt tolerance

Table 3 and Table 4 are the viscosity of different polymers under the condition of standard salinity and high salinity.

Table 3. Viscosity of polymer under standard salinity.

| Concentration, ppm | A  | B  | C  | D  |
|-------------------|----|----|----|----|
| 1000              | 19.22| 13.66| 33.11| 17.56|
| 1500              | 41.36| 48.14| 86.38| 41.73|
| 2000              | 75.43| 155.56| 195.14| 88.42|

Table 4. Viscosity of polymer under high salinity conditions.

| Concentration, ppm | A  | B  | C  | D  |
|-------------------|----|----|----|----|
| 1000              | 13.84| 8.88| 18.54| 9.66|
| 1500              | 31.02| 34.18| 58.74| 25.04|
| 2000              | 64.12| 85| 128.79| 57.47|

3.3. Shear resistance

According to the viscosity data of the four polymers before and after shearing, the viscosity of the polymer after shearing is greatly reduced. Therefore, when evaluating and screening polymers, not only the viscosity-concentration curve, but also the viscosity-concentration curve after shearing should be examined. Generally speaking, the viscosity of the polymer after shearing corresponds well to the
viscosity before shearing. However, there are exceptions, such as polymer D. The viscosity of the polymer D after shearing is higher than that before shearing.

4. Conclusions
(1) The results of laboratory experiments show that the viscosity-concentration curves of the four polymers have obvious regularity, all of which are conventional polyacrylamide, and no abnormal structure of polymers is found. In terms of viscosity-increasing performance alone, polymer C is relatively best and D is relatively the worst. In terms of shear resistance, polymers A and D are excellent, and C is the worst. After the polymer C is sheared, the relative viscosity loss is relatively large, but the absolute viscosity after shearing is still high. Under the experimental conditions, the salt resistance of the four polymers can meet the requirements.

(2) The factors affecting the viscosity of the polymer used for flooding include the molecular weight of the polymer, the concentration of the polymer, the salinity of the configuration water, temperature, and formation shear. The bulk viscosity of the polymer in the viscometer is different from the apparent viscosity when moving in the porous medium. When the shear rate is low, the two are more consistent, and when the shear rate is high, the difference between the two is obvious. When evaluating polymers, it is necessary to examine their viscosity-increasing properties, as well as their resistance to formation shear and salt tolerance.

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