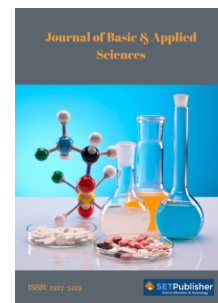




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## Experimental Study on Early Polymer Injection Timing of Heavy Oil Reservoir in Bohai Sea

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### Abstract:

The polymer flooding of ordinary heavy oil reservoirs in Bohai Sea can improve the crude oil recovery by advancing the injection time of polymer flooding. The better the injection time is, the higher the enhanced recovery is, and the greater the income is. Based on Bohai Oilfield, the polymer application system was characterized in the laboratory, and then polymer flooding experiments were carried out at different times using one-dimensional core model. The results show that: 1) polymer AP-P4 can establish good mobility control ability (RF=107, RRF=28.5) under the target reservoir conditions; 2) Under the experimental conditions, the best time for polymer injection is to switch to polymer injection after 0.203PV water injection, and the oil recovery can be increased by 27.73%. Early polymer injection technology is very beneficial to polymer flooding in offshore oil fields.

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## 1. INTRODUCTION

Polymer flooding is one of the most mature EOR techniques applied in medium heavy oil reservoirs. The objective of the process is to improve the mobility contrast between the oil and the aqueous phase, and hence improve the displacement sweep efficiency [1-3]. There are several successful large-scale polymer floods have been reported, Such as Da Qing [4, 5] and Sheng Li [6] in china, Pelican lake in Canada [7]. It is mean that although polymer floods have been generally applied in medium and light oils, there are some field tests where polymer flood is considered for heavier oil reservoirs. The bohai oil reservoir (in china) is a medium heavy oil reservoir. The viscosity average is about 70mPa·s. For water flooding in heavy oil reservoirs, the swept volume by water during a pilot flood turns out to be very limited due to an excessively high water/oil mobility ratio and serious fingering. About 60-70% oil is remained in the formation after water flooding. In order to improve the recovery in the bohai oil reservoir, the polymer flooding tests ware started in 2003 [8].

The life of platform is limited in offshore, to obtain the maximum recovery factor during the life of platform is very important. In china, there are some researches on the polymer injection timing in offshore, but researches are mainly carried out by numerical simulation method. For example, Zhang Xiansong [9] used reservoir numerical simulation to analyze that the optimal polymer injection time of offshore oilfield is 20% water cut. He Chunbai [10] believed that the polymer injection time was 0% water content through indoor experiment analysis. Jiang Shanshan [11] thinks the water cut is 60% through reservoir numerical simulation analysis. Whether the numerical experiment or the physical experiment researched on the early polymer flooding, early injection polymer would get more recovery increase, more daily oil production per ton polymer and more profit during the life of the platform. There are also many field tests indicating that early injection polymer can improve the success rate of production. Now, although early injection polymer is better for EOR is becoming a consensus of the geologists in petroleum engineers, there isn't an uniform about the optimized injection timing, because there are different injection timings in the research, such as researching the injection timing when the water cut is 60%, 70%, 80%, 90%, he thought the optimized injection timing is water cut 60% [11]; when the water cut is 20%, 40%, 60%, 80%, the optimized injection timing is water cut 20%

[12]. Recently, more and more researches indicated that the optimized injection timing is that the water cut is 0% [13,14], but that time didn't mean the polymer can direct injection. The reason is the direct injection of the polymer would make up the big problem for injection. Professor Shi [15, 16] used the relative permeability curve to analyze the polymer injection timing in his research. He thought the polymer injection should be before the increased rate of the water cut is to the maximum in the core/field. Based on the petrol-gas permeation fluid mechanics, this time of the water cut is still 0% in the exit/output liquid. Because of this time is too long in the field, we can't get the right time to inject the polymer.

Bohai Oilfield is a typical offshore oilfield in the world that carries out polymer flooding, and the research based on it can provide support for field application. Therefore, this paper takes the formation water, reservoir porosity (permeability, porosity) and polymer solution (AP-P4) of Bohai Oilfield as the research objects. The shear degradation during polymer injection is fully considered, and the percolation ability of polymer solution in porous media is first characterized. Then, oil displacement experiments at different times are carried out to obtain the best injection time for polymer flooding in ordinary heavy oil reservoirs in Bohai Oilfield.

## 2. EXPERIMENTAL STUDIES

### 2.1. Materials

- 1) Experimental brine: the experimental brine is prepared with distilled water, the brine compositions are shown in Table 1.
- 2) Experimental polymer: AP-P4 polymer is used in this study. Its molecular structure contained three monomers, including the main monomer (acrylamide and acrylic acid), hydrophobic associative monomer, with a molecular weight of 18 million, a solid content of 88%, as well as a hydrolysis degree of 23.6% [17].
- 3) Experimental crude oil: Oil used in the experiment is made by diesel and dehydrated crude oil from target offshore oil field based on a certain proportion, the viscosity is 70mPa·s at temperature 65°C.
- 4) Experimental core: The core are made up by the silica sand in certain pressure, the types is a

**Table 1: Brine for Aqueous Solution Preparation and Displacement Composition**

ions	Na <sup>+</sup> , K <sup>+</sup>	Mg <sup>2+</sup>	Ca <sup>2+</sup>	Cl <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	HCO <sub>3</sub> <sup>-</sup>	CO <sub>3</sub> <sup>2-</sup>	TDS
Concentration, mg/L	3091.96	276.17	158.68	14.21	311.48	85.29	5436.34	9374.12

**Figure 1:** One-dimensional homogeneous model.

dimension of 2.5 cm in diameter and 50 cm in length. The model used in this study is shown in Figure 1. The core porosity is about 30% and original oil saturation maintained mainly around 81%-83%. The permeability is around 1900mD-2100mD. Those models had good repeatability which would make a small impact on the experimental results.

## 2.2. Experimental Program

### 2.2.1. Effect of Shear on Apparent Viscosity of Polymer Solution

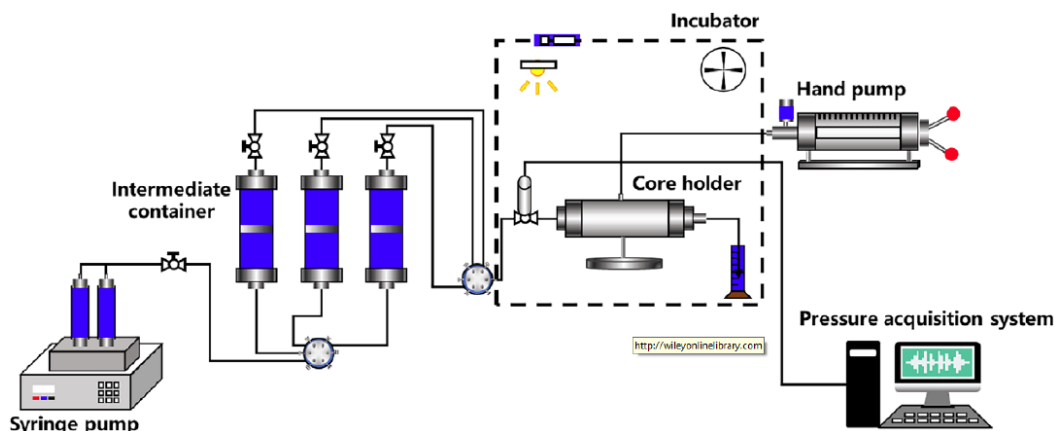
The viscosity concentration curve of polymer before and after shearing can be used to preliminarily characterize the change of solution viscosity under the influence of shearing and dilution after the system is injected into the formation. The polymer solution is injected into the Waring blender and sheared by the Waring blender at 3500 rpm for 20s. Polymer solution viscosities before and after shearing using a Waring blender are measured using a Brookfield DV-III viscometer with a shearing rate of  $7.34s^{-1}$  at 25°C.

Then, the curve of the viscosity–concentration relationship is plotted to calculate the retention rate of viscosity [18].

### 2.2.2. The Mobility Control Ability of Polymer Solution after Shearing in Porous Media

The core test process is shown in Figure 2 [19].

The concrete steps are as follows: (1) The sand pack is vacuumed and saturated with the synthetic brine. Porosity is calculated based on the weight difference before and after the sand pack is saturated with brine. Absolute permeability is obtained by injecting brine at three different flow rates and calculated according to Darcy's Law. The permeability is approximately 2000 mD, and the porosity is approximately 30%. (2) When synthetic brine is injected at a rate of 3.0 ml min<sup>-1</sup>, the stabilized pressure difference across the sand pack is recorded and denoted as  $\Delta P_b$ . (3) Polymer solution (after shearing) is injected at the set speed, and the stable pressure difference is recorded as  $\Delta P_p$ . Afterward, the brine injection is switched on. The stable pressure difference of the brine injection at this stage is

**Figure 2:** Flow characteristics of the displacement experimental process.

**Table 2: Experiment Program**

Program	Water flooding	Polymer flooding	Subsequent water drive
1	Water flooding at 0.068PV	Polymer injection 0.3PV, concentration of 1750mg/L, viscosity after shearing is 58mPa·s	Subsequent water drive to water cut of 95%
2	Water flooding at 0.141PV		
3	Water flooding at 0.203PV		
4	Water flooding at 0.270PV		
5	Water flooding at 0.364PV		

denoted as  $\Delta P_a$ . (4) Pressure values are recorded at two locations as shown in Figure 5 for the entire experimental process. (5) According to the definitions of RF and RRF, these parameters are calculated as follows:

$$RF = \frac{\lambda_w}{\lambda_p} \tag{1}$$

and:

$$RRF = \frac{K_w}{K_f} \tag{2}$$

**2.2.3. Oil Displacement Experiment Steps**

The experimental procedures are as follows: a) the models are made by silica sand; b) Permeability is measured with gas, Weighing dry weight  $m_1$ ; c) The model is saturated with Experimental brine, then Permeability is measured with Experimental brine and the wet weight  $m_2$  is Weighed; d) the model porosity is calculated,  $V=(m_2-m_1)/\rho$ ; e) Oil is injected into the model at different flow rates (0.1ml/min, 0.2ml/min, 0.5ml/min, 1ml/min), ensure the oil Saturated fully; f) Aging the core of saturated crude oil for two days; g) Carry out oil displacement experiment. First, water drive a certain amount of PV. When the time for polymer injection is reached, inject 0.3PV of polymer solution, and then Subsequent water drive until the water content reaches 95%. The injection timing are after water flooding 0.068 PV, 0.141PV, 0.203PV, 0.270PV, 0.364PV. Detailed program is given in Table 2.

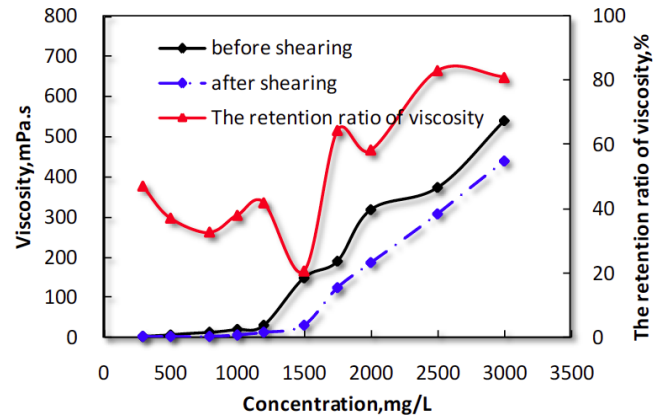
**3. RESULTS AND DISCUSSION**

**3.1. The Thickening Property and Anti-Shearing of Polymer Analysis**

Figure 3 is shown that the relationship between the concentration and the viscosity.

In the field test, the concentration of the polymer is 1750mg/L. From Figure 3, the viscosity of AP-P4

increased slowly with the increasing polymer concentration before the polymer concentration is 1500mg/L, and then the viscosity increased swiftly. Go through the shearing, the viscosity of polymer is reduced to a certain extent. But the retention ratio of viscosity is still more than 60% in the higher concentration. This means that the polymer solution AP-P4 at the applied concentration has a higher solution viscosity when it flows through porous media. This concentration can be used to analyze its mobility control ability in porous media.



**Figure 3:** the relationship between the concentration and the viscosity at 65 °C.

**3.2. Mobility Control of Polymer Analysis**

From the experiment of percolation characteristic to get the resistance factor (RF) and the residual resistance factor (RRF), the results are shown in Figure 4 and Table 3.

From Figure 4, the polymer solution has a good injection during the injection PV is increased, the entrance pressure and intermediate pressure both increased in the beginning and then stay in steady state; in the process of the subsequent water flooding, the pressure dropped rapidly. The seepage situation is very good. The result of the higher RF and RRF is shown in Table 2; it indicated that AP-P4 had a good ability of mobility control in this condition. Thought the

analysis of the polymer performance, the hydrophobic associated water polymer is useful for the polymer flooding in bohai oil reservoir. This also laid the foundation of polymer solution for subsequent oil displacement experiments at different times of polymer injection.

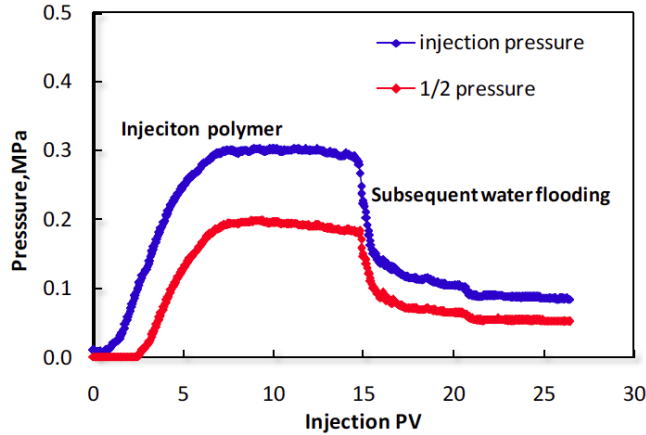


Figure 4: The flow characteristics of the polymer solution.

Table 3: The Resistance Factor and the Residual Resistance Factor of AP-P4 Polymer

polymer type	Permeability, mD	RF	RRF
AP-P4	2123	107	28.5

### 3.3. Effect of Polymer Injection Timing on Recovery

Thought the experiment, the results of the total recovery and the accumulated injection volume (PV) are shown in Table 4.

From Table 4, there are different recoveries in different injection timing. the recovery of the early polymer flooding is more than the pure water flooding at least 22%. With the polymer injection timing advanced to water flooding 0.203PV, the total recovery increased and total PV needed is reduced. But injection polymer

Table 4: Polymer Injection Timing Experimental Results

Injection timing	Recovery (water cut 95%)	Accumulated injection volume, PV (water cut 95%)
Water flooding 0.068PV	65.10	1.95
Water flooding 0.141PV	66.60	1.89
Water flooding 0.203PV	67.90	1.97
Water flooding 0.270PV	66.57	2.02
Water flooding 0.364PV	63.11	2.09
Pure water flooding	40.17	1.70

when the water flooding 0.203PV (water cut is 0%), the recovery is highest, total recovery is 67.90% and the total PV needed is 1.97PV. During the physical experiment, we found that appropriate amount of water is helpful for the polymer flooding. Amount of water injection is used to communicate flow channel, and then injection polymer would expend swept volume of water injection on the basis of the water flooding. Amount of water injection in the reservoir would build a low mobility ratio and contribute to the polymer mobility control.

Although the experiment end up to the water cut is 95%, the effect of the platform life lead to the reservoir production time is decreasing. The injection rate is 0.035PV/a, then 30 years will injection water 1.05PV. Therefore, Effect of polymer injection timing on recovery of the end of the platform life is shown at Figure 5.

The recovery is the highest when the water flooding 0.203PV. That indicated early polymer injection time is an optimized time. The optimized injection polymer time is the water flooding 0.203PV in the condition of the bohai homogeneous reservoir.

### 3.4. Effect of Polymer Injection Timing on Water Cut

From Figure 5, after water breakthrough, water cut increased fast during water flooding period. The polymer injection changed the trend of the water cut, there are two trends of the water cut: One is the water breakthrough time delay; the other is present “V” shaped trend after the injection of polymer solution. Water cut in experiments is recorded in the experiments illustrated in Figure 6.

From Figure 6, injection polymer timing is too early to control the raise of the water cut. The blue curve is better than the greed curve. During the injection time delay, the “V” shape of the water cut is weaker than

before. That is meaning that the mobility control of the polymer is becoming weak. So the best injection timing of the polymer is the water flooding 0.203PV.

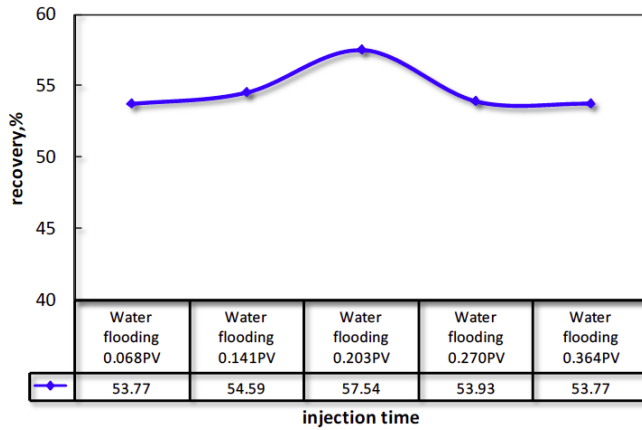


Figure 5: Effect of polymer injection timing on recovery of the end of the platform life.

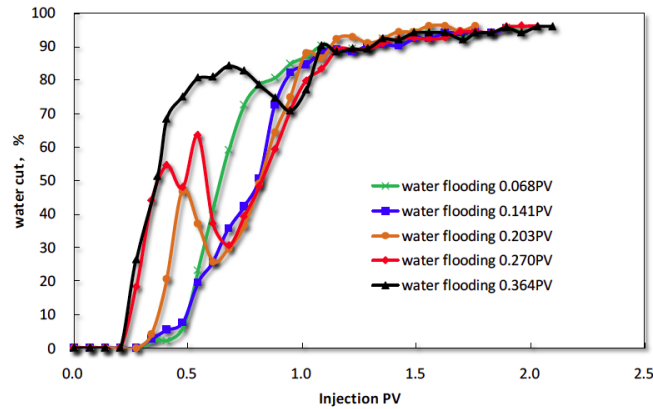


Figure 6: Water cut change curve during polymer flooding.

### 3.5. Effect of Polymer Injection Timing on Pressure

Injection pressure change with injection TV is shown in Figure 7.

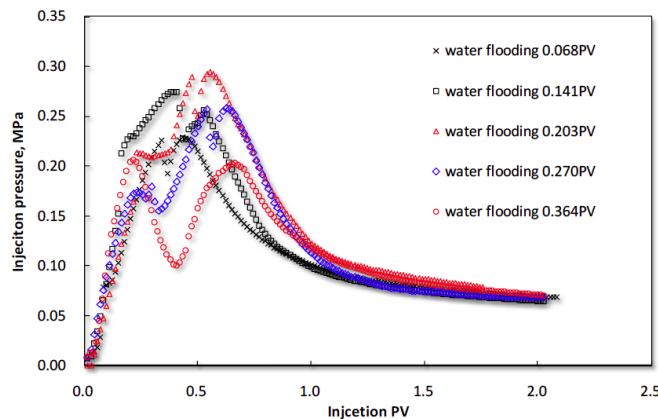


Figure 7: Injection pressure curve of polymer flooding process.

From Figure 7, Regardless of the injection problem, the bigger injection pressure just means the mobility control of polymer is better than the others during injection the core. In the experiment, the highest flooding pressure is 0.23MPa, 0.27MPa, 0.29MPa, 0.26MPa, 0.20MPa respectively. That means the best time of polymer injection is the water flooding 0.203PV, the polymer solution has a best mobility control.

## 4. CONCLUSIONS

In order to improve crude oil recovery as much as possible within the limited life span of the platform, it is necessary to begin the early injection polymer in the polymer flooding in the offshore. In the early injection polymer in crude oil reservoir, it will get a higher recovery percent of reserves at the initial stage of oilfield development. The hydrophobic associated water polymer solution (AP-P4) of optimal injection timing in the condition of homogeneous model is around 0.203 PV of water flooding.

## FUNDING

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