Experimental study on the effect of polymer concentration and slug size on recovery degree in hyper-permeability reservoir

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Abstract. Aimed at the characteristics of high porosity and high permeability reservoir, used the indoor physical simulation method, the experiment of polymer flooding with different polymer concentration and slug size were carried out after water flooding. The effects of polymer concentration and slug size on oil displacement were analysed. The results showed that the optimum polymer concentration was 2200ppm and the optimum polymer slug size was 0.9PV. And polymer concentration and slug size are the decisive factors influencing polymer flooding effect. Under the condition of a certain amount of injection, the higher the polymer concentration, the higher the viscosity of the polymer solution, the greater the reduction range of water content, and the higher the recovery rate of polymer flooding. Under the condition of a certain polymer concentration, the larger the size of the polymer solution slug, the greater the reduction of water content, and the higher the recovery rate of polymer slug flooding.

1. Introduction
Since the 1960s, polymer flooding has been widely used in many oil fields, and over 200 oil fields or blocks around the world have been tested for polymer flooding. In order to determine the optimal technical and economic effects of polymer flooding, many scholars[1-5] have studied the effects of the parameters of polymer on the oil recovery degree, such as the relative molecular weight, mass concentration, injection speed, dosage, injection method, slug size and reservoir physical property. Using core experiment and numerical simulation method, Chun Huh[6] gives the experimental results of direct polymer flooding and post-water polymer flooding, which shows that the residual oil saturation of direct polymer flooding is lower than that of post-water polymer flooding.

This paper is based on actual production demand in the field, high porosity and permeability reservoirs are simulated by filling quartz sand with sand pipes, and using crude oil from ×× fields, experiments on polymer flooding under different polymer concentrations were carried out, and experiment on oil displacement of polymer slug under different sizes of polymer slug was carried out. Then the effects of polymer concentration and slug size on recovery are analysed. Finally the polymer concentration and slug size suitable for mine production are optimized.

2. Experimental design

2.1. Experimental material
The particle size range of quartz sand filled with sand tube is 80 ~ 100 mesh, and the permeability is about $1500 \times 10^{-3} \mu m^2$ and the porosity is about 0.27. The simulated oil is taken from the second oil production plant of xx oil field. The simulated formation water is 3% KCL solution. Polymers are polyacrylamide with a molecular weight of 3 million.

2.2. Experimental methods

Experiments are carried out to Used different concentration of polymer solution to drive the simulated oil in the sand filled pipe, experiments are carried out in order to study the effect of polymer concentration on recovery degree. And then to compare the added value of the recovery in the polymer flooding stage. Finally, to select the optimal polymer concentration. The experimental process is shown in figure 1, and the specific experimental steps are as follows:

1. The pipe was filled with quartz sand and both ends of the plug were fixed.
2. Standard brine was injected into the sand filling tube at a constant speed of 0.1ml/min until there is no bubble at the outlet end of the filling pipe. In the meantime, the volume of the discharge gas at the outlet end is recorded as $V_p$ (the pore volume).
3. The simulated oil was injected into the sand filling tube at a constant speed of 0.1ml/min until there is no water at the outlet end of the filling pipe. At the same time, the volume of water discharged from the outlet is recorded as $V_{oi}$ (the original oil volume). The original oil saturation is the result of original oil volume ($V_{oi}$) divided by pore volume ($V_p$).
4. At a constant speed of 0.1ml/min, standard brine was injected into the sand filling pipe until the oil could not come out at the outlet end. At the same time, the volume of oil discharge at the outlet end is recorded. The recovery percent of water flooding stage can be obtained by dividing the volume of oil displacement ($V_o$) by the original volume of oil content ($V_{oi}$).
5. At a constant speed of 0.1ml/min, a polymer solution of a certain concentration was injected into the sand filling tube until the oil could not come out at the outlet end. The polymer flooding experiments with concentrations of 1400ppm, 1800ppm, 2200ppm, 2600ppm and 3000ppm were successively completed independently. At the same time, the volume of oil discharged at the outlet was recorded, and the recovery percent of polymer flooding stage was obtained by dividing the volume of oil discharged by the original oil volume.

Figure 1. Experimental flow graph

Experiment on the influence of polymer slug size on recovery degree is to inject a certain number of PV into the sand filled pipe after the water flooding experiment, then to compare the improvement of different slug sizes to the stage of slug drive, finally to choose the best slug size. The concentration of polymer solution is the best concentration obtained by the polymer concentration optimization experiment. The experimental process is shown in figure 1, and the specific experimental steps are as follows:

1. Repeat steps (1) to (4) for polymer concentration optimization.
2. By using the optimal polymer concentration for the polymer concentration optimization experiment, the polymer slug with a certain number of PV was injected into the sand filled pipe, and
then drove with standard saline until the oil could not be produced at the outlet end. The oil displacement experiment of polymer slug was completed. And the slug sizes were 0.1 PV, 0.3 PV, 0.5 PV, 0.7 PV and 0.9 PV polymer solutions. At the same time, the volume of oil discharged at the outlet was recorded, and the recovery percent of polymer slug flooding stage was obtained by dividing the volume of oil discharged by the original oil volume.

3. Analysis of experimental results

3.1. Effect of polymer concentration on recovery percent
The results of enhanced oil recovery by polymer flooding at different concentrations are shown in table 1 and figure 2. The recovery percent of water flooding stage is 63.51% ~ 69.42%, the recovery percent of polymer flooding stage is 6.88% ~ 13.22%, and the recovery rate is 70.39% ~ 82.64%.

Under the experimental condition, the recovery percent tends to be stable in the process of water flooding, when the displacement is about 1.5PV. In the process of polymer flooding, oil is produced when about 0.6pv polymer solution is injected, and oil output stage is concentrated between 0.6pv and 1.2pv after polymer injection (as shown in figure 2). All polymer flooding with different concentrations has the effect of improving the recovery rate. With the increase of polymer concentration, the increase of recovery degree gradually increases, and the rapid rise occurs when the concentration is 2200ppm. In the processes of polymer flooding with different concentrations, the decreasing amplitude of water content gradually increases with the increase of polymer concentration, and the maximum decreasing amplitude of water content is 38.27% (as shown in figure 3). When the concentration is 2200ppm, a steep drop occurs. So it is considered that the concentration of 2200ppm is the best concentration value for oil displacement in polymer solution.

| Polymer concentration (ppm) | Oil saturation (%) | Recovery ratio (%) | Water flooding | Polymer flooding | Final recovery |
|-----------------------------|-------------------|--------------------|----------------|------------------|---------------|
| 1400                        | 87.53             | 63.51              | 6.88           | 70.39            |
| 1800                        | 78.85             | 67.97              | 7.86           | 75.84            |
| 2200                        | 74.64             | 65.84              | 11.76          | 77.60            |
| 2600                        | 84.93             | 68.89              | 12.67          | 81.56            |
| 3000                        | 78.74             | 69.42              | 13.22          | 82.64            |

Figure 2. Injected volume effect recovery percentage

Figure 3. Injected volume effect water cut

3.2. Influence of polymer slug size on recovery degree
The results of experiments under different slug sizes using polymer solutions with a concentration of 2200ppm are shown in table 2 and figure 4. The recovery degree of water flooding stage is 64.13% ~ 68.96%, the recovery degree of polymer flooding stage is 8.33% ~ 10.17%, and the recovery rate is
73.01% ~ 78.63%.

Under the experimental condition, the recovery degree tends to be stable when the displacement is about 1.5PV. In the oil flooding process of polymer slug, oil is produced after injection of about 0.6pv of polymer slug, and oil output stage is concentrated between 0.6pv and 1.3pv after injection of polymer (as shown in figure 4). In the process of polymer slug flooding with different sizes, the decreasing amplitude of water content gradually increases with the increase of polymer slug size, and the maximum decreasing amplitude of water content is 26.28% (as shown in figure 5). Polymer with different slug sizes can improve oil recovery during oil displacement. With the increase of slug size, the recovery degree is increasing.

| Slug size (ml) | Oil saturation (%) | Recovery ratio (%) | Water flooding | Polymer flooding | Final recovery |
|---------------|-------------------|--------------------|----------------|-----------------|---------------|
| 0.1PV         | 77.26             | 65.00              | 8.33           | 73.33           |
| 0.3PV         | 73.85             | 64.13              | 8.88           | 73.01           |
| 0.5PV         | 72.92             | 67.14              | 9.14           | 76.29           |
| 0.7PV         | 82.74             | 68.96              | 9.67           | 78.63           |
| 0.9PV         | 77.80             | 67.42              | 10.17          | 77.59           |

4. Conclusions
Under experimental conditions, the concentration of 2200ppm is the best concentration value because the recovery degree increased rapidly and the water content decreased rapidly when the polymer concentration was 2200ppm. With the increase of slug size, the recovery degree is increasing. The optimum polymer slug size is 0.9PV, which is the largest injected polymer slug size.

Polymer concentration and slug size are the decisive factors influencing polymer flooding effect. Under experimental conditions, the higher the polymer concentration, the higher the viscosity of the polymer solution, the greater the reduction range of water cut, and the higher the recovery rate of polymer flooding. And, the larger the size of the polymer solution slug, the greater the reduction of water cut, and the higher the recovery rate of polymer slug flooding.

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References
[1] WANG D M, CHENG J C, WU J Z, et al. (2005) Application of polymer flooding technology in Daqing Oilfield. ACTA PET ROLEI SINICA, 26(1):74-78.
[2] XIA H F, WANG D M, HOU JR, et al. (2002) Study on the mechanism of polymer solution with visco elastic behavior increasing microscopic oil displacement efficiency. ACTA PET ROLEI SINICA, 22(4): 60-65.
[3] XIA H F, WANG D M, HOU J R, et al. (2002) Effect of viscoelasticity of polymer solution on oil displacement efficiency. Journal of Daqing Petroleum Institute, 26(2): 109-111.
[4] WANG G, XIA H F, WANG D M, et al. (2007) Effect of visco elasticity of HPAM solution on residual oil film. Journal of Daqing Petroleum Institute, 31(1): 25-29.
[5] WANG W Y. (1995) Utilizing Viscoelastic effect to enhance polymer displacement efficiency. Fault-block Oil & Gas Field, 2(5): 27-29.
[6] CHUN H, GARY A P. (2008) Residual oil saturation from polymer floods: laboratory measurements and theoretical interpretation. SPE 113417.