A Study On Optimization of Water-Viscosity Reducer-Polymer Combination Injection in Ordinary Heavy Oil Reservoirs

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Abstract. According to the characteristics of extremely high viscosity and poor fluidity of heavy oil in Chenjiazhuang 25 block of Shengli Hekou Oil Production Plant, a sand filling pipe model was made, based on the results of simulated displacement test, the chemical agents such as viscosity reducer and polymer provided by Shengli were used to explore and evaluate the chemical agent dosage, injection mode and chemical agent combination displacement mode with the recovery rate and cumulative water cut as indicators. The final experimental results showed that the optimal injection amount of viscosity reducer was 0.3 PV. The final recovery ratio could be effectively improved by mixing polymer with viscosity reducer, and the final recovery ratio of the mixed injection of polymer and viscosity reducer was 10 percentage points higher than that of the separate injection of polymer and viscosity reducer. Through conversion injection and alternate injection experiments, it was finally determined that the best combination injection mode of chemical agent was to mix polymer and low interfacial tension oil displacement agent first and then to change into mixing polymer and viscosity reducer. The injection volume of the two slugs before and after the conversion was 0.15 PV respectively, and the total injection volume of the chemical agent was 0.3 PV. The injection timing of the chemical agent was selected after 1 PV of water flooding.

1. Introduction
China's heavy oil reserves are extremely rich, and more than 70 heavy oil fields have been discovered at present. Due to the high viscosity and poor flow performance of heavy oil, the exploitation and utilization of heavy oil are limited [1]. In general, heavy oil has strong temperature sensitivity. Shengli Oilfield is one of the major heavy oil producing areas in China, and heavy oil production plays an important role in stabilizing production [2]. About 900 million tons of ordinary heavy oil reserves in Shengli Oilfield are developed by water flooding [3]. Due to the high water-oil mobility ratio, the recovery of heavy oil by water flooding in Shengli Oilfield is less than 18%, and the reserves of ordinary heavy oil reservoirs with recovery less than 25% reach 375 million tons [4]. At present, the oil recovery rate is 0.33%, the recovery percentage is greater than 17%, and the water cut is greater than 92%, which has reached the later stage of water flooding development [5].
Emulsified viscosity reducer used in heavy oil recovery is generally a high-efficiency surfactant, which is different from the surfactant flooding mechanism in conventional tertiary recovery [6]. The conventional oil fields have low viscosity and low permeability. Surfactants mainly act to reduce the interfacial tension between oil and water and change the wettability of rocks, so that rocks change from lipophilic to hydrophilic, oil droplets are easier to peel off from rocks and also reduce the flow resistance when oil is displaced by water [7]. However, heavy oil fields have high permeability and high viscosity of crude oil, so it’s hard to flow. The main function of surfactant is to reduce viscosity of crude oil and thus increase production [8]. Considering the problems of rapid rise of water cut, small sweep efficiency, low production, difficulty in oil increase in the later stage of water flooding and low recovery of water flooding, the water flooding recovery can be improved by adding viscosity reducer [9]. This study will optimize the displacement experiment by simulating, analyzing and testing the viscosity reducer’s viscosity reducing effect, providing basic data for understanding the influence of viscosity reducer’s injection mode on heavy oil development.

2. Experimental materials and instruments
Polyacrylamide powder, low interfacial tension oil displacement agent (SL-B1), viscosity reducer (SL-B2) and heavy oil sample taken from Shengli oilfield.

Experimental instruments include rotational viscometer, thermostatic box, advection pump, high-pressure intermediate container, sand filling pipe, precision pressure gauge and measuring cylinder, etc.

3. Experimental step
(1) Prepare simulated oil and simulated formation water. The viscosity of the simulated oil is 700 mPa·s at 70°C. The simulated formation water is the same as that in heavy oil blocks.

(2) Sand filling models are made with sand filling pipes. According to different sand filling ratios, sand filling models with permeability of 1.5D, 3D and 4.5D are filled out, and the pore volume and porosity of each sand filling model are obtained by weighing method. After filling sand, the dry weight of the sand filling pipe is first weighed, and then the sand filling pipe will be saturated with water. During this period, Darcy's law has been used to calculate the permeability and verify whether this sand filling meets the requirements. If the permeability calculation results differ greatly from the required permeability, it is necessary to refill the sand. If the permeability value is relatively close, the wet weight of the sand filling pipe will be weighed, and the different value between the wet weight and the dry weight is the pore volume of the sand filling pipe.

(3) The experimental process has been completed and shown in figure 1.

Figure 1. Experimental process figure
In figure 1: 1. water container 2. advection pump 3. high pressure intermediate vessel (simulated oil) 4. intermediate container with piston (viscosity reducer) 5. intermediate container with piston (simulated water) 6. pressure gauge 7. sand filling pipe 8. measuring cylinder

(4) As the sand filling pipe has been saturated with water, part of the water in the sand filling pipe will be displaced in the process of saturating oil, so the volume of displaced water is the original oil content in the sand filling pipe.

(5) Turn on the advection pump, displace the sand filling pipe full of saturated oil with a constant flow rate of 0.3 mL/min, measure the displaced oil-water mixture with a measuring cylinder, and read the volumes of oil and water respectively after fully standing still.

4. Experimental results and discussion

4.1. Effect of slug size of single injecting viscosity reducer on displacement

The viscosity reducer’s concentration is 0.3 % by mass, and the timing of injection of viscosity reducer should be selected after one PV of water flooding. The size of viscosity reducer slug is 0.2 PV, 0.3 PV and 0.4 PV, respectively. The experimental results are shown in figure 2.

As can be shown from figure 2, the recovery rate rises with the increase of viscosity reducer’s injection slug. The recovery rate of heavy oil is the lowest when 0.2 PV viscosity reducer is injected and the highest when 0.4 PV is injected. However, after water flooding to 10 PV, the recovery rate of injecting 0.3 PV viscosity reducer is 63.28 %, the recovery rate of 0.4 PV viscosity reducer is 64 %. The recovery of viscosity reducer injected with 0.4 PV is less than 1 percentage point higher than the recovery of viscosity reducer injected with 0.3 PV. Therefore, it can be considered that increasing the injection amount of viscosity reducer slug after a single injection amount has reached a certain level has no obvious effect on enhancing recovery. Therefore, it can be considered that a single injection of 0.3 PV viscosity reducer has the same viscosity reduction effect as a single injection of 0.4 PV viscosity reducer. According to the practical and economical requirements in the field, the optimum injection amount of viscosity reducer in this experiment has been determined to be 0.3 PV.

4.2. Comparative experiment on mixed and separate injection of viscosity reducer and polymer

The concentration of the prepared polymer solution is 1500 mg/L, and the concentration of the prepared viscosity reducer solution is 0.3 % by mass. According to the viscosity reducer’s injection quantity evaluation experiment, the polymer and viscosity reducer’s injection quantity in this experiment has been determined to be 0.3 PV. Therefore, the injection amount of chemical agent in separate injection experiment is designed to be 0.15 PV for polymer, 0.15 PV for viscosity reducer. In a single viscosity reducer’s injection evaluation experiment, the highest recovery rate is 64 %. The
reason is probably that the viscosity of heavy oil in this experiment is too high, which makes the fluidity difference between heavy oil and viscosity reducer solution larger, and some viscosity reducer solution does not fully play the role of viscosity reducer. It is considered that the polymer has the effect of improving the fluidity ratio. Therefore, in the separate injection experiment, the chemical injecting sequence is designed to inject 0.15 PV for polymer first and then 0.15 PV for viscosity reducer. Whether it is a separate injection experiment or a mixed injection experiment, the timing of chemical injection is selected after one PV of water flooding. The experimental results are shown in figure 3 and figure 4.

![Figure 3](image1.png)

**Figure 3.** Comparison chart of recovery ratio between mixed injection and separate injection.

![Figure 4](image2.png)

**Figure 4.** Comparison chart of cumulative water cut between mixed injection and separate injection.

From the recovery ratio comparison chart, it can be seen intuitively that the recovery ratio of polymer and viscosity reducer mixed injection is higher than that of separate injection. Moreover, compared with separate injection, mixed injection can reduce the water content of produced liquid at the outlet more. This is mainly due to the synergistic effect of polymer and viscosity reducer when they are mixed [10]. The polymer itself has the function of improving the fluidity ratio, mixed with viscosity reducer can reduce the fluidity of viscosity reducer, reduce the loss of viscosity reducer and increase the effective contact time between viscosity reducer and heavy oil. The viscosity reducer
plays the role of viscosity reduction, reducing the viscosity of heavy oil and greatly increasing the fluidity of the oil phase. Therefore, the mixed injection mode can greatly reduce the water-oil fluidity ratio. So the displacement mode of mixing polymer with viscosity reducer should be adopted.

4.3. Conversion injection and Alternate injection

There are mainly three kinds of chemicals used in this subject, namely viscosity reducer, polymer and low interfacial tension oil displacement agent. The main purpose of the experiment is to find out a displacement method of high-efficiency combined injection of the above chemicals through the experiment results. Through the previous experiments, it has been determined that the optimum injection amount of chemical agent is 0.3 PV, and the most effective injection method is mixed injection. Therefore, this group of experiments will introduce low interfacial tension oil displacement agent, and a displacement method of polymer plus viscosity reducer (P+B2) and polymer plus low interfacial tension oil displacement agent (P+B1) conversion injection has been designed. The timing of chemical injection is still selected after water flooding for one PV. The injection amount of P + B1 and P + B2 is 0.15 PV respectively, thus ensuring that the total injection amount of chemical agent is 0.3 PV. The results of the conversion injection should be related to the injecting sequence, so there will be differences between "P + B1 to P + B2" and "P + B2 to P + B1".

The so-called alternate injection is to inject each slug in half on the basis of the conversion injection. The sequence of alternate injection is: P + B1→P + B2→P + B1→P + B2. Because the injection quantities of P + B1 and P + B2 are both 0.15 PV in conversion injection, in order to ensure the same amount of chemicals, the size of each chemical slug is set to be 0.075 PV in alternate injection. The experimental results of alternate injection are compared with conversion injection, as shown in figure 5 and figure 6.
From the recovery ratio comparison chart, it can be seen that the recovery ratio of alternate injection is between the recovery ratios of two kinds of comparison injection. The displacement mode (P + B1 to P + B2) in which polymer and low interfacial tension oil displacement agent are mixed first and then converted into polymer and viscosity reducer has the highest recovery rate among the three, although there is no obvious difference in the final cumulative water cut. However, it can be seen from the cumulative water cut comparison chart that the cumulative water cut decreases the most when the injection of chemical agent starts after one PV of water flooding with "P + B1 to P + B2" injection method. Therefore, the injection mode of "P + B1 to P + B2" after water flooding for one PV is the best combination injection and displacement mode of chemical agents. The main reason is that the low interfacial tension oil displacement agent injected first has the effect of reducing the interfacial tension between oil and water, so that the mixed solution of viscosity reducer and polymer injected later can fully contact with heavy oil to play the role of viscosity reduction.

5. Conclusions

(1) The viscosity reducer’s slug size has a significant effect on recovery, but when it is more than 0.3 PV, the recovery rate increases slowly.

(2) The displacement effect of viscosity reducer combined with polymer is better than that of viscosity reducer used alone, and it is better than that of viscosity reducer and polymer injected separately, which is similar to the synergistic system of polymer and surfactant. In this process, the polymer plays its role of improving fluidity ratio, making the viscosity reducer fully contact with heavy oil and the viscosity reducer gives full play to the viscosity reducing effect, thus increasing the final recovery rate by a lot.

(3) After viscosity reducer’s injection, the recovery rate has a relatively obvious increase with the injection amount, which shows that the slope of the curve becomes larger. The water cut increases gradually with the injection amount, but suddenly decreases after the viscosity reducer has been added. It can be understood that the viscosity of heavy oil is reduced due to the addition of viscosity reducer, so the flow capacity of oil is enhanced and the flow resistance is reduced, and with the increase of viscosity reducer’s injection, the recovery rate correspondingly increases within a certain range.

(4) Through the experiments of conversion injection and alternate injection, it can be seen that the recovery rate of the displacement mode which is first mixing polymer and low interfacial tension oil displacement agent and then changing to mix polymer and viscosity reducer agent (P + B1 to P + B2) is the highest among the three, and the cumulative water cut decreases the most when chemical agent
is injected after water flooding for one PV. Therefore, the injection mode of "P + B1 to P + B2" after water flooding for one PV is the best combination injection and displacement mode of chemical agents.

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