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Research Article

The Research on High Concentration Polymer Flooding Experiment in Small Well Spacing after Polymer Flooding Rising to Economy Limit Water Cut

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Abstract: After polymer flooding, the difficulty of exploiting the potential for residual oil has increased further. Although high concentration polymer flooding can improve recovery further, the field testing shows that the injection and production is hard after the injection of high concentration polymer, so it is difficult to drive effectively, which limits the development of the high concentration polymer flooding. For the exacerbation of production decline after polymer flooding in the S pilot site PI1-2 layer of Daqing oilfield, the combination of high concentration polymer flooding and pattern infilling was presented, the laboratory experiments and numerical simulation was proceeded to study injection parameter of high concentration polymer flooding experiment in small well spacing. Research showed that injection of polymer with molecular weights of 25 millions and concentrations ranging from 2500 mg/L to 3000 mg/L were better in this block. The water cut rising to economy limit water cut of 98% after polymer flooding, and then injecting 0.5PV with concentration of 2500 mg/L polymer, the development effect was best. It could enhance oil recovery by 8.1% on basis of polymer flooding. Through optimizing the well pattern, the 106m five-spot areal well pattern was confirmed as infilled well pattern of high concentration polymer flooding. This well pattern had higher control degree on sand bodies, and it could meet the requirements of injection and production.
Keywords: Polymer flooding, Limit water cut, Small well spacing, High concentration polymer

INTRODUCTION

The main reservoir of Daqing oilfield has good physical properties, low water salinity, low formation temperature; polymer flooding had achieved good results [1].Water cut in late polymer flooding rose quickly, polymer flooding turned subsequent waterflooding, due to the mobility ratio of the injection medium changing, the injecting liquid basically formed a inefficient or invalid water circulation channel [2], and soon reached the limits of water cut 98%. After polymer flooding, formation heterogeneity enhanced and the distribution of remaining oil was fragmented and complex [3], and further development became difficult.

High viscoelastic, concentrations and molecular polymer flooding with could be used after polymer flooding for further enhanced oil recovery, but the injection difficulty occurred after high concentration polymer in similar blocks field tests. During the test, although a large number of measures of increasing by injection had been taken, but the contradictions of injection difficulties were still prominent, high concentrations of slug was difficult to form an effective driven, and oil wells had small effect. Therefore, the research on shortening well spacing trials and high concentration polymer flooding was carried out. In this paper, combined layer PI1-2 in Daqing oilfield S block condition, laboratory experiments and numerical simulation methods were used to determine high concentration of polymer flooding injection parameters, well pattern, well spacing and injection solutions. This study has some significance for site implementation of enhancing oil recovery after polymer flooding.

MATERIALS AND METHODS

Reagents and experimental conditions

The polymer used in experiments was partially hydrolyzed polyacrylamide, produced by Daqing Refining & Chemical Company, relative molecular mass was 2500×10^4. The salinity of simulated formation water was 4000 mg/L. The viscosity (about 45℃) of simulated oil was 10 mPa.s. Experimental conditions were at 45℃. Cores were artificial columnar cores, of which permeability are 200×10^{-3} μm^2, 500×10^{-3} μm^2, 800×10^{-3} μm^2. The artificial flat cores model of 30cm×30cm×4.5cm, which was simulated by five-spot well pattern, high, medium and low layers' permeability were about 200×10^{-3} μm^2, 500×10^{-3} μm^2 and 800×10^{-3} μm^2, and core coefficient of variation of core was 0.72.

Experimental Methods

Using analog saline formulated 5000 mg/L polymer mother liquor and then diluted solution for the concentration of the test object. Before the experiment, the polymer solution was subject to shear treatment and filtration, the polymer was sheared to make its viscosity retention rate to 60%, after shearing the polymer solution was filtered with 75 μm membrane.

Determination of resistance factor and residual resistance factor

Using the simulated formation water of salinity 4000 mg/L, and saturated formation water after vacuumizing core, to determine pore volume cores; then carry water flooding at constant flow rate 0.3 mL/min, according to the data of pressure at both ends of the import and export of core, to determine water permeability of cores with Darcy's law. Then the polymer solution were injected at the same speed, until the pressure across the core stability, resistance coefficient was measured. Finally, turning into subsequent water flooding when the pressure is stable, measured residual resistance factor.

Flooding experiment

The core model was vacuumized for four hours, then saturated the simulated formation water, to determine the porosity. Oil flooding water until no water in model and calculated the original oil saturation. Keeping water flooding rate at 0.3 mL/min until water cut reached 98%, and calculated the degree of recovery. Carry out the test of first slug polymer flooding, the polymer's average molecular mass of 12×10^4, the concentration of 1500 mg/L, the subsequent water flooding was carried out after injecting slug 0.67 PV until water cut reached to 98%, calculate the degree of recovery. High concentration polymer flooding was carried out, the molecular weight of 25 million, calculate the degree of recovery.

RESULTS AND DISCUSSION

High concentration polymer injection performance tests

After polymer flooding, when high porosity and permeability reservoir was injected polymer molecules with small radius, easy to form a polymer channeling [4], resulting in the cycle of injected polymer invalid. During the design of flooding program, under the conditions of injection pressure allowed, the high molecular weight and high concentration of the polymer solution should be used [5]. On the one hand, the viscosity of the high concentration polymer solution was much higher than normal concentration, the ability to expand more swept volume was enhanced, it can improve mobility ratio effectively. On other hand, high concentration polymer solution having a greater flexibility to improve microscopic oil displacement efficiency, and therefore has better oil displacement effect [6]. Combined with the experience of injecting high concentration polymer at similar block and features of small wells pacing injection, measure resistance factor and residual resistance factor of polymer concentration of 2000 mg/L, 2500 mg/L, 3000 mg/L, 3500 mg/L and 4000mg/L, the experimental results were shown in Table 1.

Table 1: Resistance factor and residual resistance factor of polymer

Permeability ($\times10^{-3}\mu m^2$)		200		500		800	
Polymer concentration (mg/L)	**Viscosity after Shear (mPa.s)**	**Resistance factor**	**Residual resistance factor**	**Resistance factor**	**Residual resistance factor**	**Resistance factor**	**Residual resistance factor**
2000	85.8	80.3	11.3	68.1	8.4	55.0	6.7
2500	115.2	92.8	13.4	80.6	10.8	64.7	8.6
3000	171.6	118.4	15.7	96.7	12.1	78.5	10.2
3500	138.6	147	18.6	110.8	15.2	89.9	12.5
4000	177.6	Block	Block	133.7	18.5	108.5	15.9

According to the results, with the increase of core permeability, the resistance factor and residual resistance coefficient decreases, the main reason is permeability increasing, accessible pore volume increased, and the cross-section which polymer molecules could go through increased, the adsorption retention of polymer solution system was reduced, thereby leading to a reduction in injection pressure. As the polymer concentration increases, the resistance factor and residual resistance factors, the main reason is that with the polymer concentration increases, the viscosity and elasticity increase as well, the polymer's adsorption and trap in the porous media increased, resulting in a injection differential pressure increases. Inject the polymer whose concentration is 3500 mg/L into the core, whose permeability is 100×10^{-3} μm^2 and then result in clogging, inject the polymer whose concentration is 4000 mg/L into the core whose

permeability is 200×10^{-3} μm^2 and then result in clogging. Studies have shown that: with the increase of the concentration of the polymer solution, changes in pore structure of the core led to reduce the pore volume of the large pores, while increase at the small pores of next level. Therefore, the high concentration of the polymer can play role in plugging large pore at some extent and adjusting injection profile. From these considerations of injectivity and adjusting the injection profile, the polymer injected in this block should be less than the maximum concentration of 3500 mg/L, 2500 mg/L or 3000 mg/L polymer can be selected.

Experiments on effect of high concentrations polymer flooding

Combined with the actual development status of the test area, the core flooding experiments were carried out. When water cut reaching to 98% in subsequent water flooding, the cores were injected 0.3 PV, 0.4 PV, 0.5 PV and 0.6 PV of concentration was 2000 mg/L, 2500 mg/L, 3000 mg/L and 3500 mg/L of high concentration polymer solution. Results of injecting 0.5 PV different concentrations of polymer are shown in Table 2.

Table 2: The experimental results of injecting 0.5PV different concentrations of polymer

Core	Oil saturation (%)	Water Flooding degree (%)	Degree of recovery in polymer flooding (%)	High concentration of polymer concentration (mg/L)	Degree of recovery in high concentration polymer flooding (%)	Recovery ratio (%)
p-9	67.2	35.1	18.4	2000	6.2	59.7
p-10	68.1	36.4	17.7	2500	8.1	62.2
p-11	67.8	36.7	18.1	3000	8.8	63.6
p-12	68.6	35.8	18.6	3500	9.1	63.5

According to the results, with the number of PV increase, the degree of recovery by high-concentration polymer flooding increases, but the amount of injected polymer to 0.5PV, the increase degree of recovery is small, so choose the amount of polymer injected to 0.5PV. With the polymer concentration increasing, recovery gradually increased, when increasing the polymer concentration from 1000 mg/L to 2500 mg/L, the degree of recovery increased obvious. After polymer flooding reached to the limit water cut of 98%, inject 0.5 PV polymer and concentration is 2500 mg/L, the recovery of high concentration polymer was 8.1%, the recovery by injecting 0.5 PV polymer whose concentration is 2500 mg/L was increased by 1.9%, larger than the 2000 mg/L, the recovery by injecting 0.5 PV polymer whose concentration is 3000 mg/L and 3500 mg / L was not increased largely, compared with the 2500 mg/L. So choose the high concentration polymer injected volume of 0.5 PV, injection concentration of 2500 mg/L.

Optimization of well pattern and injection solutions

On the basis of Daqing oilfield S block PI1-2 reservoir geological features detailed studies, the geological model of the test area was established. Using STARS modules of CMG software for high concentrations polymer flooding, well pattern is optimized and injection schemes are preferred.

Determination of well pattern

Original polymer flooding well pattern used 212m five-point method area well, due to the high concentration of high viscoelastic polymer systems, oil resistance coefficient was large, after injection of a high concentration of polymer injection pressure rises quickly, injection pressure increased significantly. The pilot test at a class of block ,which had been conducted a high concentration of polymer flooding, showed that under the conditions that injection well spacing was 237 m, after injection of 0.16 PV high concentration polymer, injection difficulty appeared, the high concentration slug was difficult to form an effective drive. Therefore, high concentration polymer flooding well pattern was optimized, studies showed that in order to ensure injection and recovery is better after high concentration of polymer injection, well spacing should be reduced to 100 m~150 m. The final solution is: The polymer flooding wells turned injection, and new wells were drilled on the four corners of the well pattern with 106m and basic well site, constitute producer-injector spacing 106m five-spot area pattern.

Determination of the injection scheme

Combined with the injection case of high concentration polymer flooding, injection capability of polymer flooding stage, and numerical simulation results, the determinate injection rate of high concentration polymer flooding is 0.18 PV/a. Simulation results of injection parameters showed that: development effects and economic benefits of injecting 0.5 PV concentration of 2500 mg/L of polymer was the best, water cut went down 5.82%, degree of recovery during high concentrations of polymer flooding stages was 8.05%. Therefore, the test program finalized was that the molecular weight of the polymer was 25×10^4, the concentration of injection was 2500 mg/L, the injection rate was 0.18 PV/a, injected pore volume was 0.5 PV.

CONCLUSIONS

- Conduct high concentrations of polymer flooding after polymer flooding, under the conditions that site of injection pressure was allowed, should try to choose a high molecular weight and a high concentration of the polymer solution, according to the test area geology, conduct injection performance test of different polymer solution concentrations in different permeability cores, the results showed that: injection performance of 25 million molecular weight, the concentration of 2500 mg/L~3000 mg/L polymer in this block was better.

- Five-spot well pattern flat core model of artificial flooding experiments show that: After polymer flooding to 98% moisture content after injection of high concentrations of polymer, the development effect of injecting 0.5PV 2500mg/L polymer was the best, can improve recovery on the basis of a polymer flooding by 8.31%.

- For the injection difficulties in the process of high concentration polymer flooding and the problem that high concentration slug can hardly form the effective driving, methods have been proposed that drill of infill wells and reduce the well spacing, establish that the encrypted well pattern is 106m five-spot area well pattern, the well pattern could make full use of the original polymer flooding injection wells, connectivity rate in three directions on sand and connectivity rate of one class both increased.

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