Application and Evaluation of Ternary System Deep Profile Control Technology

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Abstract. The development process of ASP flooding is strong in stages, and the contradictions in each injection stage are prominent. In the profile adjustment stage, there are still some wells and layers with poor plugging control effect, and the injection system is inefficient and ineffective, which not only causes the waste of high-cost injection system, but also can not effectively displace the remaining oil, which affects the expansion of swept volume and enhanced oil recovery. Therefore, deep profile control technology should be adopted to further assist profile control adjustment, but conventional profile control agents are not applicable due to the existence of alkali in ternary injection system. In this paper, the type of profile control agent suitable for ternary injection system is optimized by laboratory test, and the principle of well and layer selection is optimized. The profile control opportunity is summarized by comparing the profile control effects of four ternary industrial blocks. Through deep profile control technology, the inter-layer and intra-layer contradictions in an industrial block of ASP flooding were alleviated, and the utilization ratio of ASP system in reservoir production degree was effectively improved, and the development effect was improved.

Keywords: Ternary compounding, Block, Deep profile control.

1. Introduction

After entering the pre-slug, the weak alkali ternary industrial block of a second-class oil layer in Sazhong Development Zone of Daqing Oilfield has prominent development contradiction, and the phenomenon of unbalanced plane injection pressure and unbalanced production well effect appears. It mainly shows that the injection pressure of some well groups rises slowly, the breakthrough phenomenon of high permeability interval is serious, the production of thin and poor reservoirs is poor, the water cut of connected production wells decreases slowly, and the concentration of production agent rises rapidly. In some well groups, the injection parameters were adjusted many times. The injection viscosity reached 75.4mPa.s at the highest (the average injection viscosity of the whole area was 45mPa.s), which still could not improve the uneven production of oil layers. The study area urgently needs deep profile control to ease development contradictions.
2. Timing of profile control
ASP flooding has strong stages and irreversibility. How to utilize ternary composite system with high quality and maximize swept volume by means of deep profile control measures needs to be studied. In ASP flooding block, it is necessary to carry out profile control when the pressure is unbalanced at the initial injection stage, when the water cut is low, when the water cut drops slowly, and when the profile turns back and the production agent breaks through during the water cut recovery period. However, the field practice shows that profile control is implemented in different chemical flooding stages, and the effect of the measures obtained is quite different. Compared with six ternary industrial blocks that have implemented deep profile control, the development objects are all Class II oil layers, and the injection-production well pattern adopts the five-point method. The oil layers of profile control wells in each block are similar and have comparability. In comparison, in order to reduce the influence of dynamic characteristics in each stage of chemical flooding, the statistical data are all compared with the indicators in the corresponding stages of the whole region. At the initial stage of polymer injection, in Block A, the average water cut of profile control wells connected with production wells decreased by 2.3%, and the cumulative oil increase of well groups was 1327t. In Block B, Block C and Block D, the average water cut of profile control wells connected with production wells decreased by 3.9%, 4.1% and 5.8% respectively. The accumulated oil increase of well groups is 3024t, 3571t and 4137t respectively, and the profile control is implemented in block e and block f during the water cut recovery period. The average water cut of production wells connected with profile control wells decreased by 1.2% and 1.5% respectively, and the cumulative oil increase of well groups was 873t and 997t respectively. Comparing the above data, it can be concluded that profile control measures have the best effect during the water cut decline period of ASP flooding block.

Table 1. Comparison of profile control effects in different stages

| Blocks    | Implementation stage of profile control | Well spacing | Single well pressure increase after profile control (MPa) | The producing degree of oil layer increased (%) | Average water cut of surrounding wells decreased (%) | Accumulated oil increase of well group (t) |
|-----------|----------------------------------------|--------------|----------------------------------------------------------|-----------------------------------------------|-----------------------------------------------|---------------------------------------------|
| Block 1   | Initial injection stage                | 125m         | 1.3                                                      | 15.1                                          | 2.3                                           | 1327                                         |
| Block 2   | Water cut decline period               | 150m         | 1.2                                                      | 13.9                                          | 3.9                                           | 3024                                         |
| Block 3   | Water cut decline period               | 175m         | 1.1                                                      | 15.8                                          | 4.1                                           | 3571                                         |
| Block 4   | Water cut decline period               | 175m         | 1.1                                                      | 14.3                                          | 5.8                                           | 4137                                         |
| Block 5   | Water cut recovery period              | 125m         | 0.9                                                      | 12.8                                          | 1.2                                           | 873                                          |
| Block 6   | Water cut recovery period              | 125m         | 1.1                                                      | 14.7                                          | 1.5                                           | 997                                          |

The author thinks that in order to achieve the best profile control effect, it is necessary to closely combine the fine geological research results and the change law of well group dynamic data at the initial stage of polymer injection, and accurately determine the profile control objects, so as to avoid premature determination of profile control objects, resulting in dynamic and static inconsistency. Profile control is carried out in the initial stage of pre-slug-main slug, so as to control and plug the high permeability interval where the high-resolution and high-viscosity polymer system still can't play the role of profile adjustment, and the contradiction between layers is prominent, thus improving the production degree of oil layer. The remaining oil in thin and poor layers is displaced, so that profile control well groups can enter the stage of oil wall formation together with other well groups in the main slug stage, thus
maximizing the utilization rate of injection system and further achieving the purposes of expanding swept volume and enhancing oil recovery.

3. Optimization evaluation of profile control agent
In view of the characteristics of alkali and surfactant in ASP flooding reservoir, and high pH value near the wellbore, profile control agents with alkali resistance and surfactant resistance should be selected. Therefore, in order to select profile control agents suitable for ASP flooding, the commonly used particle and gel profile control agents are evaluated. According to the results of laboratory experiments, better profile control and plugging effect can be achieved by adopting the slug combination of particles and gel. Because the profile control interval of profile control wells is thick at present, and the injection pressure among the wells is unbalanced, the profile control uses slug combination to control the pressure increase.

3.1. Optimization of profile control particles
QC profile control particles have better expansibility, and the elasticity and strength after expansion are better than the other two kinds of particles. After soaking in ternary solution, the median particle size increases by 2-3 times, the expansion factor is about 16 times, and the via hole strength can reach about 1.1MPa. The viscosity loss of ternary solution after particle soaking is small, and the interfacial tension can be kept at the order of × 10-3 Mn/m. At the same time, compared with the ternary blank sample, the ternary solution soaked by particles has little change in system properties.

| Code of profile control agent | Quantity (g) | Expansion time (days) | Expansion ratio (Times) | Strength of via hole (MPa) | Remarks |
|-----------------------------|--------------|-----------------------|-------------------------|---------------------------|---------|
| QC                          | 20~40        | 3                     | 16                      | 1.1                       | Good elasticity |
| WT                          | 20~40        | 4                     | 20                      | 0.7                       | The elasticity is general, and the smell is pungent |
| HL                          | 20~40        | 2                     | 13                      | 1.3                       | Inelastic, rigid particles, pungent smell |

3.2. Optimization of profile control gel
The cross-linking agents of different raw materials were evaluated by compatibility experiment of ASP flooding. The cross-linking agents of B raw materials have better compatibility with water quality and polymer in production area, and the system has higher gel strength. The gel viscosity can reach more than 7000mPa.s when the polymer concentration is 1500mg/L. Multi-component complex gel system gels in alkaline environment with PH value of 8 ~ 9, and the system can still gel in the presence of surfactant. Subsequent ternary solution has less damage to colloid, which can prolong the effective period of profile control.

| Crosslinking agent type | Crosslinking agent concentration (%) | Polymer concentration (mg/L) | Additive concentration (%) | Stabilizer concentration (%) | PH     | Gelling time (days) | Gel viscosity (mPa.s) |
|------------------------|--------------------------------------|-----------------------------|---------------------------|----------------------------|--------|-------------------|----------------------|
| A                      | 0.3                                  | 1500                        | 0.08~0.1                  | 0.1                        | 8.5~9.5| 3                 | 2172                 |
| B                      | 0.3                                  | 1500                        | 0.08~0.1                  | 0.1                        | 8.5~9.5| 2                 | 7749                 |
| C                      | 0.3                                  | 1500                        | 0.08~0.1                  | 0.1                        | 8.5~9.5| 3                 | 3644                 |
4. Principle of profile control, well selection and layer selection
At the initial stage of injection in the study area, it is necessary to closely track the pressure increase of injection wells, the production fluid, water cut and concentration of production agent of production wells. Based on the results of fine geological research, combining dynamic and static data, in the well areas with well groups with developed river sand bodies, high proportion of Class I communication and perfect injection and production, the injection wells with unbalanced production conditions, low injection pressure and high water cut of production wells in the well groups should be optimized for profile control. The specific principles of the study area are as follows: the injection pressure is 10% lower than the average injection pressure in the whole area, and the pressure space is greater than 2MPa; the water injection profile of injection wells is uneven and serious, and the water absorption ratio of high and medium water flooded layers is more than 30%; the vertical heterogeneity of injection wells is serious, and the permeability difference between layers is greater than 2.5 times; the water content of surrounding connected production wells is high, and the water content difference of well groups is large, and 50% of the produced wells contain water It is larger than the comprehensive water cut of the whole area; the reservoir development connectivity is good, the well group perfection degree is more than 50%, and the first class connectivity ratio of channel sand is more than 50%; the channel sand of injection well is developed, and the effective thickness of profile control interval is greater than 4.0m; the target layer of profile control is high and medium water flooded layer, and the permeability is greater than 0.500 μ m2.

5. Parameter design of profile control
5.1. Profile control thickness and profile control direction
According to the results of well selection and layer selection of profile control wells, combined with injection well profiles, water flooded data and other data, profile control thickness is determined as the water absorption thickness of high water flooded interval, and profile control direction is determined according to the perfection degree of sand body development.

5.2. Profile control radius and single well consumption
The injection-production well spacing in the study area is 175m. Considering the serious longitudinal heterogeneity of injection wells, the contradiction between layers and layers is different in each well. According to the pressure test after pulling out the nozzle, the profile control radius is about 1/4 ~ 1/3 well spacing, 45 ~ 55m. Single well dosage of profile control agent According to profile control thickness and oil control area, use formula ① to calculate the dosage of profile control agent.

\[ Q = S \cdot H \cdot \phi \cdot Ev \cdot Fn / 4 \] ①

Where: Q—the amount of profile control agent, m3
S—Profile control area, m2
H—Profile control thickness, m
φ—Porosity, %
Ev—Sweep coefficient
Fn—Number of profile control directions

6. Evaluation of profile control effect
According to the above-mentioned principle of selecting wells and layers, 13 wells were selected as profile control objects in the study area, and the combination of alkali-resistant microsphere profile control particles and multi-element complex gel was adopted to implement profile control during the water cut decline period, and good results were achieved. Seen from the injection end, the injection pressure of single well before profile control is lower than the regional level by 1.8MPa, and the average injection pressure of single well after profile control rises by 1.1MPa, gradually approaching the regional level. The apparent water absorption index decreased by 1.5m3/MPa by 11.12%, and the production ratio of oil layer increased from 63.1% to 78.9%, thus achieving the purpose of adjusting injection
profile. From the production end, the water cut of the surrounding connected production wells decreased slowly before profile control, and the production wells achieved remarkable results after profile control for 5 months. The water cut gradually decreased to 88.3%, which was always lower than that of the whole region. The daily oil increase of a single well was 6.4t, the oil increase multiple was 3.5, the cumulative oil increase was 27,062 tons, and the recovery ratio of profile control wells increased by 1.84%.

Table 4. 13 wells were selected as profile control objects in the study area

|                         | Injection pressure (MPa) | Apparent water absorption index (m3/d·MPa) | Production ratio of oil layer (%) | Minimum water cut (%) | Average daily oil production per well (t) |
|-------------------------|-------------------------|-------------------------------------------|----------------------------------|-----------------------|-----------------------------------------|
| Before profile control  | 9.1                     | 13.5                                      | 63.1                             | 95.8                  | 2.5                                     |
| After profile control   | 10.2                    | 12                                        | 78.9                             | 88.3                  | 8.9                                     |
| The whole region        | 10.7                    | 9.2                                       | 77.1                             | 92                    | 6.2                                     |

7. Conclusions
1. In order to achieve the best profile control effect, it is necessary to determine the profile control object in the early stage of polymer injection by closely combining the fine geological research results and the change law of well group dynamic data, and to implement profile control in the early stage of pre-slug-main slug, so as to maximize the utilization rate of ternary injection system, and then achieve the best profile control effect.

2. Practice has proved that the combination of alkali-resistant microsphere profile control particles and multi-element complex gel can adapt to ternary injection system, alleviate the contradiction between layers and layers in the study area, increase the pressure increase of injection wells, promote the balanced production of oil layers, slow down the breakthrough of chemical agents, promote the effectiveness of connecting production wells, and achieve the purpose of further expanding swept volume and improving oil recovery.

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