Analysis on the Effect of High Concentration Slug before Stopping Polymer Injection

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Abstract: With high concentration or high molecular weight with high concentration plugging slug can enhance recovery further, which make full use of high concentration polymer viscoelastic before stopping polymer flooding. These layers are usually well developed and connected, and has a certain pressure rise space. We optimized two blocks for polymer flooding in this block, the two blocks inject middle molecular weight with high concentration and high molecular weight with high concentration plugging slug respectively, we optimized the molecular weight, and find out that the 25 million plugging slug is better than the 7 million. The study has important guiding significance for late stage of polymer flooding.

1. Introduction

A industrial zone is the first industrial block in our factory, this block exploited horizon is P13, which covers an area of 6.79 km² and geological reserves is 634.38×10⁴t, underground pore volume is 1263.11×10⁴m³. The well spacing is 150m apart with five-spot pattern, and the total number of Wells was 228, which including 101 injection Wells and 127 production Wells. The average thickness of a single well is 10.57m and the net thickness is 8.27m. The block began polymer flooding in March 2009 and entered the water pick-up period in March 2013, this block water content ascend more than 95% in 2015. The residual oil distributes very dispersedly at the stage, so has little potential for further exploitation [1].

According to the study of numerical simulation, injecting sealing plug before stopping polymer flooding can make the water fall further [2], and the production wells have a secondary effect, we optimized 3 and 4 blocks which wells develop and connect relatively good, the two blocks inject middle molecular weight with high concentration and high molecular weight with high concentration plugging slug respectively. From the experiment, the injection profile got obvious improvement and the water cut falls. By analysis of the effect of different Wells, we optimize the molecular weight, and find out that the 25 million plugging slug is better than the 7 million. It can be used as a reference for subsequent blocks.

2. Parameter Optimization of Mathematical Model

According to the analysis of the block, the plugging slug test before stopping polymer flooding was carried out in 3 and 4 blocks. The 3 fault block covers an area of 1.19 km², and geological reserves is 119.13×10⁴t, and the pore volume is 237.40×10⁴m³. The number of Wells is 36, which including 19 injection Wells and 17 production Wells. The average thickness of a single well is 10.9m and the net thickness is 9.2m. The 4 fault block covers an area of 1.92 km², and geological reserves is 231.93×10⁴t, and the pore volume is 461.17×10⁴m³. The number of Wells is 57, which including 26 injection Wells and 31 production Wells. The average thickness of a single well is 13.6m and the net thickness is 11.2m.

According to the study of numerical simulation [3], the molecular weight of block 3 and 4 block carried out optimization. The results shows that 3 block injecting 7 million is better than 25 million, and 4 block injecting 25 million is better than 7 million. So 3 block inject 7 million salt resistant
polymer and 4 block inject 25 million polymer.

Table 1 Comparison of molecular weight optimization of 3 fault block

| molecular weight | stopping polymer flooding | water cut 98% |
|------------------|---------------------------|--------------|
|                  | stage of oil production (10^4 t) | water content (%) | stage of oil production (10^4 t) | stage recovery (%) |
| water drive      |                           | 2.32         | 1.97 |   |
| 7 million        | 93.47                     | 13.03        | 10.94 | 18.53 | 15.56 |
| 25 million       | 93.50                     | 12.84        | 10.77 | 18.31 | 15.37 |

Table 2 Comparison of molecular weight optimization of 4 fault block

| molecular weight | stopping polymer flooding | water cut 98% |
|------------------|---------------------------|--------------|
|                  | stage of oil production (10^4 t) | water content (%) | stage of oil production (10^4 t) | stage recovery (%) |
| water drive      |                           | 3.57         | 1.54 |   |
| 7 million        | 94.58                     | 26.81        | 11.56 | 34.21 | 14.75 |
| 25 million       | 94.54                     | 26.93        | 11.61 | 34.33 | 14.80 |

According to the study of numerical simulation, both 3 and 4 flocks have the best effect when they inject the concentration of polymer are 1600mg/L, so the concentration of 1600mg/L is adopted in both zone[4] [5].

Table 3 Comparison of concentration optimization of 3 fault block

| concentration (mg/L) | at the end of injection | water cut 98% |
|----------------------|-------------------------|--------------|
|                      | stage of oil production (10^4 t) | water content (%) | stage recovery (%) | Stage of oil production (10^4 t) | stage recovery (%) |
| water drive          |                           | 2.32         | 1.97 |   |   |
| 1200                 | 93.55                    | 12.93        | 10.85 | 18.42 | 15.46 |
| 1600                 | 93.47                    | 12.98        | 10.90 | 18.52 | 15.54 |
| 2000                 | 93.52                    | 12.96        | 10.88 | 18.46 | 15.49 |

Table 4 Comparison of concentration optimization of 4 fault block

| concentration (mg/L) | at the end of injection | water cut 98% |
|----------------------|-------------------------|--------------|
|                      | stage of oil production (10^4 t) | water content (%) | stage recovery (%) | Stage of oil production (10^4 t) | stage recovery (%) |
| water drive          |                           | 3.57         | 1.54 |   |   |
| 1200                 | 94.57                    | 26.75        | 11.53 | 34.12 | 14.71 |
| 1600                 | 94.54                    | 26.93        | 11.61 | 34.33 | 14.80 |
| 2000                 | 94.54                    | 26.84        | 11.57 | 34.24 | 14.76 |

According to the study of numerical simulation [6], high concentration polymer slugs of 0.03PV is injected into both zone 3 and 4.

3. The Implementation of Plugging Slug

Through the analysis of 3 block, with a total of 12 wells can inject 7 million plugging slug. These 12 Wells injected 7 million block slug in April 2015 with injection allocation of 450 m^3 and concentration of 1537 mg/L. It was stopped in May 2015 with 0.029 PV.

Through the analysis of 4 block, with a total of 15 wells can inject 25 million plugging slug. These 15 Wells injected 25 million block slug in May 2015 with injection allocation of 825 m^3 and concentration of 1664 mg/L. It was stopped in july 2015 with 0.03 PV.
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Table 5 The single well injection scheme of plugging slug with 7 million

| Well No. | fracture pressure (MPa) | net thickness (m) | Before the plugging slug | 7 million plugging slug |
|----------|------------------------|-------------------|--------------------------|-------------------------|
|          |                        |                   | Before the plugging slug | 7 million plugging slug |
|          |                        |                   | injection pressure (MPa) | injection allocation (m³) | injection concentration (mg/L) | injection allocation (m³) | injection concentration (mg/L) |
| A1       | 13.9                   | 9.5               | 12.8                     | 80                      | 1013                         | 70                       | 1800                        |
| A2       | 13.9                   | 5.8               | 12.9                     | 30                      | 900                          | 30                       | 1300                        |
| A3       | 13.9                   | 7.2               | 13.0                     | 60                      | 1200                         | 60                       | 1500                        |
| A4       | 14.0                   | 8.2               | 8.0                      | 40                      | 975                          | 40                       | 1500                        |
| A5       | 14.1                   | 8.8               | 9.8                      | 60                      | 600                          | 50                       | 1500                        |
| A6       | 13.9                   | 12.2              | 12.8                     | 20                      | 600                          | 20                       | 1200                        |
| A7       | 14.0                   | 7.8               | 13.4                     | 25                      | 840                          | 25                       | 1200                        |
| A8       | 14.0                   | 10.1              | 12.8                     | 20                      | 600                          | 20                       | 1500                        |
| A9       | 14.0                   | 7.3               | 13.5                     | 35                      | 771                          | 35                       | 1371                        |
| A10      | 13.9                   | 12.4              | 13.4                     | 30                      | 600                          | 30                       | 1400                        |
| A11      | 14.0                   | 4.5               | 13.5                     | 20                      | 600                          | 20                       | 1200                        |
| A12      | 14.0                   | 6.8               | 13.3                     | 60                      | 1000                         | 50                       | 1800                        |
| combine  | 14.0                   | 8.4               | 12.4                     | 480                     | 869                          | 450                      | 1537                        |

Table 6 The single well injection scheme of plugging slug with 25 million

| Well No. | fracture pressure (MPa) | net thickness (m) | Before the adjustment | 25 million plugging slug |
|----------|------------------------|-------------------|-----------------------|--------------------------|
|          |                        |                   | Before the adjustment | 25 million plugging slug |
|          |                        |                   | injection pressure (MPa) | injection allocation (m³) | injection concentration (mg/L) | injection allocation (m³) | injection concentration (mg/L) |
| B1       | 14.0                   | 14.9              | 11.8                   | 110                     | 1173                         | 60                       | 2000                        |
| B2       | 14.0                   | 13.6              | 13.5                   | 70                      | 814                          | 60                       | 1800                        |
| B3       | 13.9                   | 17.6              | 10.2                   | 90                      | 1067                         | 90                       | 2000                        |
| B4       | 14.2                   | 17.2              | 9.3                    | 40                      | 750                          | 60                       | 1800                        |
| B5       | 13.8                   | 7.1               | 12.7                   | 35                      | 1457                         | 35                       | 1800                        |
| B6       | 14.0                   | 13.3              | 12.7                   | 70                      | 1500                         | 70                       | 1971                        |
| B7       | 14.2                   | 11.3              | 9.4                    | 35                      | 600                          | 40                       | 1500                        |
| B8       | 14.0                   | 5.6               | 12.9                   | 100                     | 1050                         | 100                      | 1800                        |
| B9       | 14.0                   | 4.1               | 13.2                   | 30                      | 600                          | 30                       | 1500                        |
| B10      | 13.7                   | 10.5              | 13.2                   | 40                      | 750                          | 40                       | 1500                        |
| B11      | 13.9                   | 10.0              | 12.8                   | 20                      | 600                          | 20                       | 1500                        |
| B12      | 14.2                   | 10.9              | 12.2                   | 40                      | 750                          | 40                       | 1500                        |
| B13      | 14.2                   | 5.2               | 9.4                    | 115                     | 1487                         | 115                      | 2009                        |
| B14      | 14.0                   | 16.2              | 12.7                   | 30                      | 500                          | 30                       | 1500                        |
| B15      | 14.0                   | 6.6               | 13.5                   | 60                      | 600                          | 50                       | 1286                        |
| combine  | 14.0                   | 10.9              | 12.0                   | 885                     | 913                          | 1024                     | 1664                        |

4. Analysis on the Effect of Plugging Slug

After injecting plugging slug, the injection profile improves dramatically. The fluid entry ratio of poor layer increased by 6.9 percentage points from 53.2% to 60.1% that injected 7 million, and relative suction increased by 7.2 percentage points from 29.3% to 36.5%, at the same time,
the fluid entry ratio of good layer increased by 3.8 percentage points from 74.7% to 78.5%, and relative suction decreased by 7.2 percentage points from 70.7% to 63.5%.

The fluid entry ratio of poor layer increased by 9.8 percentage points from 51.1% to 60.9% that injected 25 million, and relative suction increased by 11.3 percentage points from 27.1% to 38.4%, at the same time fluid entry ratio of good layer increased by 3.9 percentage points from 76.3% to 80.2%, and relative suction decreased by 11.3 percentage points from 72.7% to 61.6%.

The water content was from 95.1% to 93.6%, which decreased 1.5% after injected 25 million plugging slug. Decrease amplitude was 0.7% above the 7 million plugging slug and was higher than
no plugging slug wells beyond 2.2%.

Table 7 Injection profile of plugging slug before and after with plugging slug

|                                     | Before and after 7 million plugging slug | Before and after 25 million plugging slug |
|-------------------------------------|------------------------------------------|-------------------------------------------|
|                                     | fluid entry ratio of poor layer (%)      | fluid entry ratio of poor layer (%)       |
|                                     | fluid entry ratio of good layer (%)      | fluid entry ratio of good layer (%)       |
|                                     | relative suction of poor layer (%)       | relative suction of poor layer (%)        |
|                                     | relative suction of good layer (%)       | relative suction of good layer (%)        |
| Before plugging slug                | 53.2                                     | 51.1                                      |
|                                     | 74.7                                     | 76.3                                      |
|                                     | 29.3                                     | 27.1                                      |
|                                     | 70.7                                     | 72.7                                      |
| after plugging slug                 | 60.1                                     | 60.9                                      |
|                                     | 78.5                                     | 80.2                                      |
|                                     | 36.5                                     | 38.4                                      |
|                                     | 63.5                                     | 61.6                                      |

Table 8 Classification of the maximum reduction of water content in plugging slug well area

| Classification of the maximum reduction of water content (%) | 7 million plugging slug | 25 million plugging slug |
|-------------------------------------------------------------|--------------------------|--------------------------|
|                                                             | Well number ratio (%)    | maximum reduction of water content (%) | Well number ratio (%) | maximum reduction of water content (%) |
| <1                                                           | 6                        | 40.0                     | 0.2                   | 4                        | 20.0                     | 0.3                     |
| 1-3                                                          | 5                        | 33.3                     | 1.3                   | 5                        | 25.0                     | 1.4                     |
| 3-5                                                          | 3                        | 20.0                     | 3.5                   | 7                        | 35.0                     | 3.5                     |
| ≥5                                                           | 1                        | 6.7                      | 5.1                   | 4                        | 20.0                     | 6.6                     |
| combine                                                      | 15                       | 100                      | 1.5                   | 20                       | 100.0                    | 3.0                     |

From the reduction of water content of single well, there were 11 wells which maximum reduction of water content exceed 3%. It accounted for 55% of the total number of oil wells, and was 28.3% higher than 7 million plugging slug.

According to the above statistics and analysis, it is believed that the effect of 25 million plugging slug is better than 7 million plugging slug. Therefore, it is recommended to use 25 million molecular weight polymers in the future plugging slug injection.

5. Conclusion

It can enhance recovery further, when inject high molecular weight and middle molecular weight with high concentration before stopping polymer flooding, it make full use of viscoelastic of polymer to displace the oil. The concentration should be higher than 1500mg/L as far as possible within the range of acceptable pressure, these layers are usually well developed and connected, and has a certain pressure rise space.

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