Study on the Limit and Time of Separated Layer Injection of Polymer Flooding in Second-class Oil Layers

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Abstract. Separated Layer Injection is widely used as an effective means of development in oilfields and the limit and time of Separated Layer Injection has a great influence on the development effect. According to the achievement of the fine reservoir description of research area, theory model is established. According to the oil displacement plan and development status of Second-class Oil Layers, the polymer flooding parameters are designed. Theory models with different permeability differential are designed, with the range of 1-6. Each model is simulated in different injection mode and separated injection timing. From the variation of water cut, remaining oil distribution and increment value of recovery rate, simulation results show that separated layer injection of polymer flooding should be applied when permeability differential reached 2. The best time of separated layer injection is related to the intensity of injection of high permeability reservoirs and low permeability reservoir. When the high permeability and low permeability oil layers have the same injection strength, Separated layer injection should be applied earlier. In the process of polymer flooding, water injection rate should not be excessively restricted on control layer injection, and it should be ensured in order to maximize the use of thick layer potential.

1. The establishment of geological model and the parameters of polymer flooding

According to the research needs, the theory model is divided into three thick layers, the first layer is divided into 4 layers, the second layer is also divided into 4 layers, the third layer is divided into 7 layers. As shown in table 1, the inner layer of the model is homogeneous with difference between the layers. The number of grids is 9375 in total and the dimension of grid is 25 * 25 * 15. It consists of 9 well groups, 25 wells, 16 injection wells and 9 production wells. 150 meters well spacing and five-spot pattern. According to the oil displacement plan and development status of second-class oil layers, the polymer flooding parameters are designed as follows: the middle molecular weight of polymer;polymer solution using a single whole slug injection and slug concentration is 1000mg/L;polymer loading of 640mg/L·PV; injection rate is 0.16PV/a; According to development status of second-class oil layers of research area, layers are divided into three intervals of polymer injection in the design of injection model. The first is control section and the following two layers are reinforcing layers. The average single well injection intensity is 6.2 m³/m·d.

Table 1. Parameters of each simulation layer.

| Layer number | layer number | porosity (%) | Initial water saturation (%) | effective thickness (m) |
|--------------|--------------|--------------|-----------------------------|------------------------|
| The first layer | 1            | 28.53        | 41.95                       | 0.3                    |
2. Design of operation scheme
In this study, 9 different models are designed. The permeability differential range is from 1 to 6, and the permeability differential of each model is like table 2. Each model is designed for commingled water injection and separated layer injection at 6 stages of polymer flooding, blank water flooding stage, initial stage of polymer flooding, water cut down stage, low water cut stage, recovery stage of water cut and follow-up water drive stage. As shown in table 3, a total of 7 simulation programs are implemented for each model and injection production ratio is maintained at 1:1.

Table 2. Model and permeability differential corresponding table.

| Model name | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 | Model 8 | Model 9 |
|------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| Permeability differential | 1.18    | 1.50    | 1.76    | 2.00    | 2.35    | 3.00    | 4.00    | 5.00    | 6.00    |

Table 3. Time and stage of polymer flooding corresponding table.

| Name                  | Time 1 | Time 2 | Time 3 | Time 4 | Time 5 | Time 6 |
|-----------------------|--------|--------|--------|--------|--------|--------|
| The time of separated injection | blank water flooding stage | initial stage of polymer flooding | water cut down stage | low water cut stage | recovery stage of water cut | follow-up water drive stage |

3. The determination of the limit and time of separated layer injection

3.1. Determination of the limit
The time of separated injection is in the blank water flooding stage, distribution map of the lowest water cut value difference between commingled water injection and separated layer injection of the different permeability differential models can be seen. With the increase of permeability differential, the improvement of displacement effect is more and more obvious compared with commingled water injection. When the permeability differential is 1.18 to 1.76, the minimum value of water cut of polymer flooding before and after separate injection is basically the same. When the permeability differential increases to 2, the minimum value of water cut is 1.08 percentage points lower than that of commingled injection. When the difference is further increased to 6, the minimum water content is 5.62 percentage points lower than that of the commingled injection. The time of other separated
injection is in accordance with the trend of this statistical result, and the decrease amplitude of the lowest water content is slightly different.

As shown in table 4, the difference of recovery value between commingled water injection and separated layer injection is analysed and the numerical simulation results show that when the permeability differential is less than 2, effect of separated layer injection is not obvious and increment value of recovery rate of each scheme is less than 0.5 percentage points. When the difference is greater than 2, effect of separated layer injection becomes more and more obvious. Therefore it is suggested that when the permeability difference is greater than 2, the separated layer injection can be carried out.

### Table 4. Increment value of recovery of each scheme.

| Permeability differential value | Time 1 increment value of recovery (%) | Time 2 increment value of recovery (%) | Time 3 increment value of recovery (%) | Time 4 increment value of recovery (%) | Time 5 increment value of recovery (%) | Time 6 increment value of recovery (%) |
|-------------------------------|---------------------------------------|---------------------------------------|---------------------------------------|---------------------------------------|---------------------------------------|---------------------------------------|
| 1.18                          | 0.00                                  | 0.00                                  | 0.00                                  | 0.00                                  | 0.01                                  | 0.02                                  |
| 1.50                          | 0.09                                  | 0.18                                  | 0.19                                  | 0.20                                  | 0.19                                  | 0.18                                  |
| 1.76                          | 0.41                                  | 0.49                                  | 0.48                                  | 0.45                                  | 0.43                                  | 0.37                                  |
| 2.00                          | 0.66                                  | 0.74                                  | 0.69                                  | 0.65                                  | 0.58                                  | 0.50                                  |
| 2.35                          | 1.16                                  | 1.23                                  | 1.14                                  | 1.03                                  | 0.94                                  | 0.78                                  |
| 3.00                          | 2.03                                  | 2.09                                  | 1.94                                  | 1.77                                  | 1.57                                  | 1.32                                  |
| 4.00                          | 3.36                                  | 3.40                                  | 3.16                                  | 2.87                                  | 2.56                                  | 2.16                                  |
| 5.00                          | 4.59                                  | 4.62                                  | 4.28                                  | 3.92                                  | 3.48                                  | 2.95                                  |
| 6.00                          | 5.72                                  | 5.75                                  | 5.35                                  | 4.89                                  | 4.37                                  | 3.71                                  |

### 3.2. Determination of time of separated layer injection

The best time of the separated injection is related to the injection strength ratio between the high permeable oil layer and the low permeability oil layer and as shown in table 5 three schemes of different ratio are designed in this study. The average injection intensity of the single well is 6.2 m³/m·D in the whole area. As shown in figure 1, the result of the first scheme is that the earlier the separated injection is carried out, the better, when the high permeability oil layer and low permeability oil layer have the same injection strength. The second scheme, the injection strength of high permeability oil layer is lower than that of low permeability oil layer. As shown in figure 2, under the ratio of injection strength of the second scheme, the optimum separated injection time is initial stage of polymer flooding.

It can be seen that the best time of the separated injection is related to the injection strength ratio of the high permeable oil layer and the low permeability oil layer. As shown in figure 3, the third scheme, with bigger difference of injection strength between high permeability oil layer and low permeability oil layer, the injection rate of the high permeability layer is excessively restricted under the injection conditions. This will result in poor development of the high permeability layer and the final recovery rate is reduced. The analysis can draw the conclusion: in the process of polymer flooding, such as blank water flooding stage, initial stage of polymer flooding, water cut down stage and low water cut stage, injection rate of the high permeability layer should not be excessively restricted and the injection quantity should be ensured in order to maximize the use of thick layer potential.

### Table 5. Injection intensity of each scheme.

| Type of oil layer         | Injection strength of scheme 1 (m³/m·d) | Injection strength of scheme 2 (m³/m·d) | Injection strength of scheme 3 (m³/m·d) |
|---------------------------|----------------------------------------|----------------------------------------|----------------------------------------|
| High permeability layer   | 6.2                                    | 5.0                                    | 3.0                                    |
| Low permeability layer    | 6.2                                    | 6.8                                    | 7.7                                    |
Figure 1. Scheme 1 distribution map of increment value of recovery.

Figure 2. Scheme 2 distribution map of increment value of recovery.

Figure 3. Scheme 3 distribution map of increment value of recovery.

3.3. Distribution law of remaining oil

Taking production well at the center of the model (permeability differential 2, injection strength of scheme 2, separated layer injection at blank water flooding) as an example, when the water cut reaches 98%, from the observation of remaining oil of the well in vertical distribution as shown in Table 6, we can see that remaining oil saturation of the first layer is similar between commingled water injection and separated layer injection, however the remaining oil saturation of the second and third layer of separated layer injection is lower than that of commingled water injection. It can be seen that separate layer injection has played a role in the use of low permeability oil layer and it can effectively alleviate the contradiction between layers.
Table 6. Distribution of longitudinal remaining oil saturation of central well.

| Layer number | layer number | remaining oil saturation of commingled water injection (%) | remaining oil saturation of separated layer injection (%) |
|--------------|--------------|------------------------------------------------------------|----------------------------------------------------------|
| The first layer | 1 | 42.05 | 44.74 |
|               | 2 | 41.20 | 42.77 |
|               | 3 | 39.21 | 40.43 |
|               | 4 | 39.51 | 40.75 |
|               | 1 | 43.35 | 42.07 |
| The second layer | 2 | 45.00 | 42.33 |
|               | 3 | 43.80 | 41.74 |
|               | 4 | 44.06 | 41.56 |
|               | 1 | 44.02 | 41.18 |
|               | 2 | 43.16 | 40.68 |
|               | 3 | 42.15 | 40.70 |
| The third layer | 4 | 44.28 | 41.52 |
|               | 5 | 43.59 | 41.12 |
|               | 6 | 44.39 | 41.76 |
|               | 7 | 45.28 | 42.40 |

3.4 Implementation of separated layer injection

The separated injection wells of polymer flooding of second-class oil layers in research area are counted. The number of injection wells is total 138, of which 112 are separated injection wells, and the rate of separated injection is 81.16%. The number of separated injection wells at all levels is shown in Table 7.

Table 7. Statistical table of separated injection well.

| Permeability differential value | The number of separated injection wells | Rate  |
|--------------------------------|---------------------------------------|-------|
| >2.0                           | 68                                    | 60.71 |
| 1.5-2.0                        | 30                                    | 26.79 |
| 1.5<                           | 14                                    | 12.50 |
| Total                          | 112                                   | 100   |

4. Conclusion

(1) With the increase of permeability differential, the effect of separated layer injection on recovery is becoming more and more obvious. It is suggested that when the permeability differential is greater than 2, the separated layer injection can be carried out.

(2) The best time of separated layer injection is related to the injection strength of the high permeable oil layer and the low permeability oil layer. When the injection strength of the high permeability oil layer is equal to that of the low permeability oil layer, the earlier the separated injection is carried out, the better.

(3) In the process of polymer flooding, blank water flooding stage, initial stage of polymer flooding, water cut down stage, low water cut stage, injection rate of the high permeability layer should not be excessively restricted and the injection quantity should be ensured in order to maximize the use of thick layer potential.
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