Practice and Understanding of Improving Recovery Efficiency of Polymer Flooding in Fault Well Area

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Abstract. In view of the problems of high development ratio of thin and poor layers and imperfect injection-production relationship in fault-intensive areas, this paper puts forward corresponding comprehensive treatment measures to further tap the reservoir potential and improve polymer flooding recovery.

Keywords: Fault development; Thin and poor layer; Injection production relationship.

1. Main problems in the development of fault-intensive blocks
There are 54 faults in the second-class oil layer in the south second west, forming 9 closed and 14 semi-closed small fault blocks. There are 9 normal faults in polymer flooding reservoirs in the west of the fourth south China Sea, which divide the block into eight independent oil-water movement areas. Due to relatively developed faults, imperfect injection and production, and complicated reservoir development, the following problems exist in development.

1.1. The single-layer outburst is serious in the well area with thick layer development
The well areas with medium-thick reservoirs in Pu-1 Formation in the west of south fourth area and Sa II7-12 Reservoir in the west of south second area are mainly developed by river sand. These wells have high water saturation before polymer injection, high water absorption ratio at the initial stage of polymer injection, and great difference in interlayer production status. The initial water cut in the well area is high, and the effect is poor. After polymer injection, the production wells in the well area will get results after polymer injection, and the effective time is 4 months behind that in other well areas, and the water cut decreases by only 5.25%, which is lower than that in the whole area by 1.34 percentage points.

1.2. The injection condition in the well area with thin and poor layers is poor
The proportion of wells developed in thin and poor layers is high. Sa II7-12 oil layer in the west of south area 4 is mainly composed of thick and stable deposits of inner front facies and outer front facies, which can be divided into seven sedimentary types according to sand body development patterns and conditions. The main sand, non-main sand and surface layer are mainly developed, and the development ratio of oil layer with single layer thickness less than 1m is higher than that of other second-class oil layers. The effective thickness of single well is mainly concentrated in 4-8m, which is lower than the average level of the whole region, and the proportion of wells is as high as 35.8%. At the initial stage of
polymer injection, this kind of wells showed small allowable injection pressure difference, and the injection difficulty wells accounted for 72.1% of the difficult wells in the whole region.

According to the statistics of water flooding data of new wells drilled in the east of South Area 4, the second-class reservoirs are mainly medium-high water flooding, with high water flooding ratio of 50.61%, medium water flooding ratio of 39.43% and low water flooding ratio of 9.96%.

Table 1. Table of drilling conditions of different sand bodies in industrial blocks of Class II oil layers

| Block          | Drilling through sandstone (m) | Effective drilling (m) | Drilling rate(%) | Proportion of oil layers with single layer thickness < 1m(%) | Thickness proportion of oil layer with single layer thickness < 1m (%) | Thickness ratio of permeability > 0.1μm2(%) |
|----------------|--------------------------------|------------------------|------------------|-------------------------------------------------|-----------------------------------------------------------------|-----------------------------------------------|
| South 2, East 2| 16.8                           | 9.3                    | 23.0             | 22.7                                            | 20.8                                                            | 23.1                                           | 74.9                                          | 33.7                                          | 70.3                                          |
| South 3, East 2| 12.3                           | 7.3                    | 24.8             | 21.2                                            | 21.9                                                            | 22.6                                           | 53.6                                          | 21.9                                          | 92.3                                          |
| South 2, West 2| 11.6                           | 6.3                    | 21.9             | 23.7                                            | 17.1                                                            | 29.0                                           | 72.1                                          | 27.6                                          | 93.6                                          |

Table 2. Drilling thickness table of various sedimentary types of the second-class oil layers in the west of south fourth area

| Sedimentary type          | Number of units | Drilling rate(%) | Effective > 0.5m main sand | Effective 0.5-0.9m main sand | Effective 0.2-0.4m non-main sand | Off-balance sheet reservoir | Total                          |
|---------------------------|-----------------|------------------|-----------------------------|-----------------------------|----------------------------------|-----------------------------|---------------------------------|
| Laminar                   | 14              | 18.65            | 6.0                         | 4.8                         | 17.48                            | 4.8                         | 3.1                             | 24.93                           | 5.7                             | 2.9                             | 19.51                          | 4.2                             | 1.4                             | 16.14                          | 4.4                             | 96.71                          | 25.2                            | 12.2                            |
| Branch-lamella transition | 2               | 10.90            | 0.3                         | 0.2                         | 7.66                             | 0.2                         | 0.1                             | 14.95                           | 0.3                             | 0.2                             | 20.09                          | 0.3                             | 0.1                             | 30.90                          | 0.4                             | 84.50                          | 1.6                             | 0.7                             |
| Dendritic                 | 1               | 7.57             | 0.2                         | 0.1                         | 9.73                             | 0.2                         | 0.1                             | 11.53                           | 0.1                             | 0.1                             | 7.57                           | 0.1                             | 0.0                             | 25.23                          | 0.2                             | 61.62                          | 0.7                             | 0.3                             |
| Thick and stable type     | 6               | 24.68            | 3.0                         | 2.0                         | 31.02                            | 2.8                         | 1.4                             | 23.84                           | 2.0                             | 0.7                             | 15.32                          | 1.4                             | 94.86                          | 9.1                             | 4.1                             |
| Poor and stable type      | 3               | 5.65             | 0.2                         | 0.2                         | 14.59                            | 0.4                         | 0.3                             | 30.21                           | 0.8                             | 0.3                             | 41.80                          | 1.2                             | 92.25                          | 2.6                             | 0.7                             |
| Thin and unstable type    | 1               | 0.54             | 0.0                         | 0.0                         | 3.96                             | 0.0                         | 0.0                             | 12.61                           | 0.1                             | 0.0                             | 27.57                          | 0.2                             | 44.68                          | 0.3                             | 0.1                             |
| Scattered type            | 1               | 3.06             | 0.0                         | 0.0                         | 1.26                             | 0.0                         | 0.0                             | 4.50                            | 0.0                             | 0.0                             | 20.54                          | 0.1                             | 29.37                          | 0.1                             | 0.1                             |
| Total                     | 28              | 10.37            | 6.5                         | 5.1                         | 15.66                            | 8.5                         | 5.6                             | 22.34                           | 9.5                             | 4.9                             | 20.42                          | 7.5                             | 2.6                             | 20.66                          | 7.8                             | 89.45                          | 39.7                            | 18.2                            |

1.3. Imperfect injection and production in fault block area

The west of the fourth south area is located in the west of Sa Ertu anticline. the buried depth of the top of Sa I formation is 758.0 ~ 935.6 m, and the depth of oil-water interface is about 1171 m. There are more developed faults in this area. There are 18 normal faults on the top of the Sa II group oil layer. The strike is NW or NEE, extending from 320 to 5,045 m, with a dip angle of 38.4 to 71.8°. The fault horizon is from Mingshui Formation to Gao IV. Group, the fault distance is 3.2 ~ 106.4m, of which there are 5 large faults with an extension length greater than 2800m. Seismic structural interpretation results of 3D development show that 10 faults have been adjusted in the new interpretation results, including 6 new small faults, 1 cancelled, 1 merged and 2 split.
Figure 1. Map of fault interpretation results on the top surface of Sa II formation structure in the west of south fourth area

Due to the dense faults, the channel sand connectivity is poor. The channel sand connectivity ratio is 57.0%, which is close to the level of the whole region, but it is mainly unidirectional and bidirectional connectivity, and the multi-directional connectivity ratio is only 15.8%, which is lower than that of the eastern region by 13.2 percentage points. The control degree of polymer flooding is 36.3%, which is 22.3 percentage points lower than the average level of the block.

1.4. The reservoir has strong heterogeneity and great difference in injection pressure
The pressure distribution is different, and the rising space is small. The allowable injection pressure difference before polymer injection is 4.84MPa, of which 40 wells distributed in low permeability areas are less than 2MPa, accounting for 16.5% of the total number of wells.

2. Research and application of comprehensive adjustment and tapping potential method
According to the characteristics of reservoir sedimentation and remaining oil distribution in fault-block areas, combined with the practical problems in polymer flooding development, the comprehensive adjustment method is studied and practiced.

2.1. Increase regulation and control in well areas with thick layer development
First, carry out different types of deep profile control. In view of the well areas with developed thick reservoirs, strong injection capacity, high water saturation, high permeability zones and perfect injection-production system in local areas, profile control was carried out in 44 wells to fully tap the potential of thick reservoirs.

Compared before and after profile control of Pu I1-4 reservoir in the west of nansisi, the average injection pressure increased by 1.5MPa, and the apparent water absorption index decreased by 0.46m3/d.m. MPa. According to the statistics of injection profiles of 5 wells before and after profile control, the effective thickness ratio of water absorption increased by 31.21 percentage points, and the water absorption status of each unit improved. The water absorption ratio of the main water absorption unit Pu I2c decreased from 52.91% before profile control to 25.57%, a decrease of 27.34 percentage points, and the vertical water absorption status in the layer was adjusted to varying degrees: Pu I1a unit changed from non-absorbent layer to absorbent layer before adjustment, and the water absorption ratio was 2.9%; The water absorption thickness and water absorption ratio of Pu I1 and Pu I4 units also increased correspondingly.

The liquid absorption ratio of the second profile control layer in the south second west decreased by 13.6%, while the effective thickness ratio of the non-profile control layer increased by 15.9%. After profile control, the injection pressure increased by 0.83MPa more than that in the whole area. The well area is fully effective, and the effect of increasing oil production and dewatering is obvious. 72
production wells in profile control well area are effective. Compared with those before profile control, the daily oil production increases by 95.1 tons and the comprehensive water cut decreases by 4.01 percentage points.

For example, Pu I1-4 oil layer produced in south 4-10-P124 well area belongs to delta distributary plain facies and inner front facies, which are mainly multi-segment and multi-rhythm. The permeability difference between the vertical upper layers is large, and the permeability difference between the layers is 3.2. The contradiction between the vertical upper layers is prominent, the water flooded thickness is large, and there is a strong water absorption unit; on the plane, the reservoir development is not balanced, so the composite ion depth profile control is implemented, and the profile control target layer Pu I22 is 3.0m thick.

After profile control, the starting pressure and injection pressure of well south 4-10-P124 increased by 1.3MPa and 1.05MPa, and the daily injected solution decreased from 205m³ to 167m³ under the same injection pressure, with a decrease of 18.5%. The water absorption thickness ratio of the whole well increased from 58.18% to 100%, the water absorption ratio of Pu I21 increased from 36.72% to 47.78%, and the water absorption ratio of Pu 22 decreased from 63.28% to 40%. Before profile control, Pu 23 and Pu I3 do not absorb water, but after profile control, the water absorption ratio reaches 9.0% and 3.22%. The relative water absorption ratio of profile control target layer has been effectively controlled, and the water absorption ratio of relatively poor oil layer has increased obviously, and the injected solution starts to advance in the medium and low permeability layer, thus expanding the swept volume of polymer in the formation and achieving the purpose of improving the water absorption profile.

After profile control, the production wells became effective one after another. The daily liquid production decreased from 661t before profile control to 404t, the daily oil production increased from 44t to 105t, and the water cut decreased from 93.8% to 74.01% before profile control. Compared with the production wells without profile control, the water cut decreased by 6.22 percentage points and the oil production increased by 1.15×10⁴t in polymer flooding stage.

![Figure 2. Water absorption profile of injection well before and after profile control](image)

![Figure 3. Comparison curve of water cut between south 4-10-P124 well area and south 4 west numerical model](image)
Second, carry out hierarchical adjustment. In view of the well area with thick oil layer development, large interlayer difference, good injection condition, high permeability zone and interlayer condition, the general change and stratification adjustment are carried out to further control single-layer outburst. Sixteen wells were injected into the south fourth west in the early stage. The injection pressure increased by 0.1MPa and the apparent water absorption index decreased by 0.154m³/d·m·MPa before and after stratification. The stratified test data of wells with earlier stratification were compared. The results show that the water absorption strength of the strengthening layer increases from 11.8m³/d·m to 22.3m³/d·m, up by 10.56m³/d·m, and that of the limiting layer decreases from 32.2m³/d·m to 14.9m³/d·m, down by 17.3 m³/d·m. At present, the water cut of the connected unmeasured production wells is 84.68%. Compared with that before layering, the monthly water cut appreciation slows down by 0.3 percentage points, and the water cut rising speed is controlled by layering injection.

2.2. Utilization measures to ensure injection in thin-layer developed well areas

First, increase measures to increase injection. In view of injection difficulties in each stage of production and polymer injection, measures should be strengthened to ensure injection capacity. Twenty-one fracturing and 24 plugging removal were carried out for thin and poor layers in fault block area. After adjustment, the decline of apparent water absorption index and apparent water absorption index were effectively controlled.

Second is to explore measures to increase injection and new technologies. In order to improve the injection ability of thin and poor layers, 8 injection wells with thin reservoir thickness, low permeability and strong plane and longitudinal heterogeneity were selected to carry out pre-flushing injection enhancement test of nano silicon. After plugging removal, the average injection pressure decreased by 1.8MPa, the pressure increase was 7.7 percentage points lower than the regional level, the injection pressure was continuously lower than the normal level, the apparent water absorption index decreased by less than 10% all the time, and the injection capacity in the well area remained good.

The third is to carry out the alternate test of different quality injection. Ten injection wells with strong heterogeneity, developed thin and poor layers, rapid pressure rise and poor injection condition in the second-class reservoir are classified into three types according to the existing research results of quality alternation.

Type a: the proportion of oil layers below A: 1m is ≥60%, and the oil layers with effective single layer ≥2m are undeveloped; Type b: the ratio of layers below B: 1m is ≥50%, and the ratio of thickness of single layer effective ≥2m is ≥50%; Type c: the effective oil layer thickness ratio over 1m is ≥80%.

According to the classification principle of differentiated well groups, the pre-selected 10 wells were injected alternately in three ways, and the slug scheme with low molecular weight and high concentration was implemented in the early stage, and the injection condition was good, and the water cut in the well area did not continue to rise.

2.3. Perfecting injection-production relationship in fault development well area

First, hole patching is explained in combination with well earthquake. According to the fault-shielded well area after seismic interpretation, combined with the existing dynamic and static data, the remaining oil-rich parts are replenished to improve the injection-production relationship in the well area.

The second is to use tracer to further verify faults. Tracer injection is carried out for the faults which cannot be determined after seismic interpretation. The existence and sealing of 6 faults are verified by monitoring 15 production wells in 4 well groups in south four west. Verification of fault sealing. Tracer monitoring technology is used to verify the existence and sealing of small faults. Four well groups were selected for testing, and 7 wells were found in 15 production wells. It was verified that there were 2 faults, 1 fault did not exist, and all four faults were closed.

Third, the use of supplementary holes in fault shielding areas. Based on the dynamic and static data and well seismic interpretation results, three well groups with imperfect injection and production and prominent contradiction were repaired. After hole repair, the daily oil production of single well increased by 4.5t, and the control degree of multi-directional polymer flooding in well area increased by 5.3%.
Table 3. Single well table of reperforating utilization effect of production wells in fault shielding area

| Serial number | Well number | Thickness of sandstone (m) | Effective thickness (m) | Make-up effective thickness | Hole patching time | Before repairing holes | Initial stage after hole patching | Opening date of well | Initial stage after hole patching | Water content (%) | Daily oil production (t) | Daily liquid production (t) | Sinking degree |
|---------------|-------------|-----------------------------|------------------------|---------------------------|--------------------|------------------------|---------------------------|-------------------|---------------------------|----------------|------------------------|------------------------|---------------|
| 1             | N1-4-P130   | 155                         | 7.5                    | 149                       | 98                 | 2013.12.09            | 108                       | 7.8               | 92.8                       | 220            | 13.12.19               | 114                    | 37.7           |
| 2             | N2-3-P126   | 19.0                        | 9.0                    | 12.9                      | 6.2                | 2013.12.11            | 57                        | 3.1               | 91.7                       | 120            | 13.12.28               | 105                    | 9.3            |
| 3             | N1-D6-226   | 20.4                        | 14.3                   | 14.9                      | 10.1               | 2013.12.09            | 15                        | 2.6               | 62.7                       | 78             | 13.12.17               | 52                     | 4.1            |

For example, well group south 1-5-P222 is located at the high point of Sa Ertu structure, and there are three normal faults, namely 1381#, 151# and 149#. The well group has a high proportion of thin and poor layers and strong reservoir heterogeneity; Complex structure and developed faults; The injection-production relationship is imperfect, and the reservoir connectivity is poor.

After well-seismic interpretation, the length of faults 1381# and 149# extended, and three faults formed semi-closed small fault blocks. Verification of fault sealing by tracer. Tracer monitoring of south1-D6-226 well and its surrounding production wells proves that three faults exist and are sealed. The four oil and water wells in the fault block area are connected, the control degree of polymer flooding of well groups is 65%, there is no multi-directional communication, and there is no production well point at the edge of the fault. Use water flooding in fault block area for one time to infill well south1-D6-226 and inject Sa II7-12 again, and use it as polymer flooding production well. After hole supplementation, the control degree of polymer flooding in fault block area increased by 11.8 percentage points and increased by 38.3%.

3. Summary

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