Practice and Understanding of Fine Control Fracturing Technology for Three Types of Sandstone Reservoirs

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Abstract: Development Zone B of Daqing Oilfield is located in the northwest of the oilfield structure and at the western end of the anticline structure in the north. The structure is relatively gentle. It belongs to sandstone reservoirs deposited by typical continental fluvial-delta facies reservoirs. There are many faults in this area, with a large fault distance. A total of 29 large and small faults are developed, all of which are normal faults. The faults have good sealing performance. The sand bodies in this area are cut into narrow strips by faults, with a small distribution area, and the phenomenon of one injection and one production or with and without injection is serious. The contradictions among and within the three types of reservoirs are prominent, and the degree of reservoir production is low. In order to study the high-efficiency tapping potential technology for the three types of reservoirs in pure oil region, technical research and experiments were carried out from 2017 to 2018. Through in-depth analysis of the main factors that affect the development effect of the three types of reservoirs in pure oil region, the technical research route with fine subdivision and large penetration ratio fracture sand control body to improve interlayer and plane contradictions as the research direction was determined, which is aimed at the difference of reservoir sand body development characteristics and injection-production connectivity in each direction, fine subdivision was carried out on the target layer in the longitudinal direction, and the reservoir sand body characteristics and injection-production relationship were combined in the plane. Fine control fracturing technology has been tried in three types of reservoirs, and initial results have been achieved. The fine control fracturing technology has been applied to two wells, with a fracturing efficiency of 100%, increasing oil production by 8.6t at the initial stage of a single well and 2186.3t at the stage. Field tests show that the fine control fracturing technology has a remarkable effect on the reconstruction and production of thin and poor reservoirs, and explores a new way to tap the potential of thin and poor reservoirs in the later period of ultra-high water cut.

1. Introduction
Development Zone B is located at the western end of the northern anticline structure. After being put into production and developed in 1964, four major wells pattern adjustments. In order to reduce the production decline, the production target is expanded from Class I oil layer to Class III oil layer. Due to the difference in physical properties of the produced oil layer, the production of each oil layer is uneven. The production ratio of sandstone thickness of oil layer with effective thickness less than 0.5m is 60.86%, which is 39.14 percentage points lower than that of Class I oil layer. It can be seen that there is still a great potential for remaining oil in this type of oil layer. It has taken 13 years for the three types of reservoirs to be put into production in 2004. During this period, measures such as hole filling and fracturing have been taken. However, the reserves have not been released to the maximum extent. The development efficiency needs to be improved urgently. It is of great significance to the
sustainable development of the oilfield and the construction of the oilfield for a hundred years to study the high-efficiency tapping technology for the three types of reservoirs.

### 2. Analysis of Factors Affecting Development Effect of Three Types of Reservoirs

#### 2.1 Influence of Reservoir Development

The three types of oil reservoirs are mainly two types of subfacies underwater distributary channel deposits, i.e. delta inner front and delta outer front. Currently, the energy of rivers into the lake is smaller than that of water distributary. Due to the characteristics of shallow lake basin and strong river energy, rivers still play a major role in sedimentation. There are three types of sedimentation: nearshore, mid-shore and far-shore.

Under the transformation of lake waves, the sand bodies deposited in the nearshore become worse in channel continuity. The sheet sand develops along both sides of the underwater channel, and mud between distributaries is relatively developed. The sand body deposits are mainly distributed in the north-south direction. The middle bank has entered the underwater environment during sedimentation, the river effect is relatively weakened, while the lake wave transformation effect is enhanced. The underwater distributary channel sand is intermittently distributed in strips. Some channel sand is transformed into lumps. The width of the channel is slightly wider and the thickness is smaller locally. The strip of sheet sand is not obvious, and the distribution area is larger, and the pinch-out area is less developed. Distant bank deposits are formed by underwater distributary channels under the transformation of lake waves, with poor continuity and distribution in the form of pods, thick lumps, etc. The channel sand scale is extremely small, and the main sheet sand has certain strip directivity, while the pinch-out area is distributed over a large area, which makes the connectivity in the continuous distribution area of sheet sand better, while the connectivity in other areas is poor. Overall, the planar heterogeneity is stronger.

### Table 1: Development Zone Utilization Statement

| Layer number (Number) | Sandstone (m) | Effective (m) | Layer number{}^<{}2.0m | Sandstone | effective |
|-----------------------|---------------|--------------|-----------------------------|-----------|-----------|
| >=2.0m                | 6             | 22.6         | 13.4                        | 100.00    | 100.00    | 100.00    |
| 1.0-2.0m              | 40            | 85.1         | 55.6                        | 85.00     | 85.43     | 83.81     |
| 0.5-1.0m              | 52            | 72.9         | 36.7                        | 73.08     | 74.76     | 77.11     |
| <=0.5m                | 140           | 141.8        | 47.9                        | 60.00     | 60.86     | 61.17     |
| Subtotal              | 238           | 322.4        | 153.6                       | 68.07     | 73.23     | 76.56     |
| Off balance sheet     | 326           | 245.6        | 0.0                         | 52.15     | 54.68     |
| Total                 | 564           | 568.0        | 153.6                       | 58.87     | 65.21     | 76.56     |

Influenced by the sedimentary environment, the sand bodies of the three types of reservoirs are developed with uneven thickness in the longitudinal direction. The thin layers with effective thickness...
less than 0.5m account for 82.5% of the total number of well intervals and have low water absorption and production capacity. The continuity on the plane becomes poor, the pinchout area of some layers is large, the connection relation between well groups is deteriorated, and the effect of water injection is uneven.

2.2 Influence of Completion Technology
The three types of reservoirs have the characteristics of thin layers and many layers. In the completion process, the current-limiting fracturing completion method is mostly adopted. It uses the difference of fracture pressure of each layer to limit the water absorption capacity of each layer by controlling the hole number and hole diameter of each layer. Limited by the technical level of the process, the previous current-limiting fracturing blocks were within four blocks, with more than 6 layers of oil layer in each block and 9-10m³ of sand addition for single layer. Due to the small sand addition amount in the field implementation process, it may not be possible to ensure that the inner layers of the block are laminated and achieve the expected effect, and the reserves of some layers cannot be released.

2.3 Distribution Law of Remaining Oil in Reservoir of Development Zone B

2.3.1 Analysis of coring well data shows that the weak unwashed ratio in the reservoir reaches 24.18%, while thin and poor reservoirs with effective thickness less than 1.0m are the main reservoirs with this potential. (Table 3)

| Thickness Classification | Strong flooding | Medium flooding | Weak flooding | Unflooded | Total |
|--------------------------|----------------|----------------|--------------|-----------|-------|
| Thickness (m)            | Proportion (%) | Thickness (m)  | Proportion (%) | Thickness (m) | Proportion (%) | Thickness (m) | Proportion (%) | Flooding thickness (m) | Water flooding ratio (%) |
| Effective≥2.0m           | 8.19           | 23.28          | 20.84        | 59.24      | 2.50      | 7.11         | 3.65         | 10.38           | 35.18                 | 31.55 |
| 2.0>Effective≥1.0m       | 0.36           | 4.97           | 3.74         | 51.59      | 1.68      | 23.17        | 1.47         | 20.28           | 7.25                  | 5.78  |
| 1.0>Effective≥0.5m       | 0.41           | 9.72           | 2.41         | 57.11      | 0.60      | 14.22        | 0.80         | 18.96           | 4.22                  | 3.43  |
| Effective<0.5            | 0.05           | 2.56           | 0.85         | 43.59      | 0.27      | 13.85        | 0.78         | 40.00           | 1.95                  | 1.16  |
| Total                    | 9.01           | 18.54          | 27.84        | 57.28      | 5.05      | 10.39        | 6.70         | 13.79           | 48.60                 | 41.92 |

2.3.2 Analysis of watered-out data of new wells shows that the oil layers of Sa I and Gao II groups with poor oil layer development conditions have a higher proportion of low water-out and have a certain residual oil potential with a lower recovery rate. However, judging from the recovery degree of each sedimentary unit, the recovery degree of GI and GII groups is relatively low, so it is also a potential for tapping the potential of thin and poor layers.

The above data indicates that the remaining potential in Development Zone B is mainly
concentrated in thin and poor reservoirs with poor reservoir development.

3. **Optimization of High Efficiency Tapping Potential Technology for Oil Wells**

According to the present development situation of the three types of reservoirs and the distribution law of remaining oil, the technical research route with fine subdivision and large penetration ratio fracture sand control body to improve interlayer and plane contradictions as the research direction is determined, and the fine control fracturing technology is optimized for testing. Fine control fracturing technology is based on fine geological research results, combined with pressure multi-layer fracturing tools to realize longitudinal fine layering control. The fracturing target layer is longitudinally changed from multi-layer general fracturing in conventional clamping section to 2-3 layers fine fracturing. On the plane, the fracture length is designed according to the sedimentary structure development, residual potential and injection-production connection relationship of sand body in the layer, so as to realize accurate control of the potential in sand body by fractures.

3.1 **Optimization of Test Well**

Development Zone B has developed 100 type III reservoir wells with injection-production ratio of 1: 1.43, average daily fluid production level of 10.4t/d, and comprehensive water content of 87.8%. It is the lowest water-driven layer system in Development Zone B and also the main layer system with water drive potential. Typical well H is selected as the test well in this formation.

3.1.1 **Thin and poor layers are developed, and the proportion of current-limiting perforation fracturing completion is high.**

Well H has 22 oil layers, only 3 of which have an effective thickness greater than 0.5m. The rest of the oil layers are thin and poorly developed layers. The current-limiting perforated completion interval accounts for 54.5% of the total number of well intervals.

| Ejection horizon | Number of shooting layers /number | Sandstone thickness /m | Effective thickness /m | Ratio of thin layer with effective thickness less than 0.5m /% | Percentage of perforation intervals by current limiting method /% | Effective thickness ratio of perforation section by current limiting method /% | Thickness ratio of sandatone in perforated section by current limiting method /% |
|------------------|----------------------------------|------------------------|------------------------|---------------------------------------------------------------|--------------------------------------------------------------------------------|--------------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| S                | 2                                | 3.5                    | 2.0                    | 50                                                            | 0                                                                              | 0                                                                              | 0                                                                              |
| P                | 5                                | 2.9                    | 0.5                    | 100                                                           | 100                                                                            | 100                                                                            | 100                                                                            |
| G                | 15                               | 11.9                   | 2.4                    | 93.3                                                          | 46.7                                                                           | 16.7                                                                           | 44.5                                                                           |

3.1.2 **Low Oil Production Level per Unit Effective Thickness**

The cumulative oil production per unit effective thickness of well H before fracturing is 1376t/m, 700t/m lower than the cumulative oil production per unit effective thickness of the same well pattern in the whole region, indicating that there is more unused reserves in the reservoir.
3.1.3 Incomplete Injection and Production of Sealing Well in Development Zone

Test well H is located on the boundary line of the development zone. From the well map, it can be seen that only water injection wells in the east and south directions provide driving kinetic energy for the well. Due to imperfect injection and production, there is no displacement energy in the southwest, west and northwest directions and there is residual potential.

3.1.4 Low control degree of water flooding in potential zones

Based on the understanding of fine geological research results, Well H has identified four potential zones. From the connection between potential zones and water injection wells, it can be seen that there is basically no good connection with Well 2#. Two of the four zones are not connected, and two zones are connected in three types. The connectivity with Well 3# is good but only in one direction on the plane. As a result, the control degree of water flooding in potential zones of Well H is only about 25%, and the remaining 75% of potential has not been effectively displaced.

| potential interval | H well development | sandstone thickness /m | effective thickness /m | completion mode | 2# reservoir development in connected water injection wells | Connectivity with 2# water injection well | 3# reservoir development in connected water injection wells | Connectivity with 3# water injection well |
|--------------------|---------------------|------------------------|------------------------|-----------------|----------------------------------------------------------|------------------------------------------|----------------------------------------------------------|------------------------------------------|
| A paragraph        | Sheet sand          | 1.3                    | 0.3                    | Limited-flow perforation | Off balance sheet | disconnection                                           | Off balance sheet                          | Two classes of connected relations       |
| B paragraph        | Off balance sheet, riverside | 2.1 | /                      | Limited-flow perforation | Sheet sand       | Three classes of connected relations                     | Off balance sheet                          | A class of connected relations            |
| C paragraph        | Sheet sand, riverside | 2.0                    | 0.7                    | Limited-flow perforation | Pinch out        | disconnection                                           | Sheet sand                                 | A class of connected relations            |
| D paragraph        | Main sand edge      | 2.5                    | 0.8                    | Ordinary perforation  | Off balance sheet | Three classes of connected relations                     | Off balance sheet                          | Two classes of connected relations       |

3.2 Process Optimization and Parameter Optimization

The Sabei Development Zone is constrained by in-situ stress, and the fracture strike is horizontal during fracturing. The relationship between yield increase multiple and fracture geometric parameters and conductivity can be calculated by analytical formula [19]:

$$PR = \left( \frac{K_h W_f}{K_f W_f} \right) \left[ \frac{1 + \frac{K_h}{K_f}}{1 + \frac{K_h}{K_f} + \ln \left( \frac{R_e}{r_w} \right)} \right] $$

In the formula, $R$——the multiple of production increase; $K_f$——Fracture Permeability, md; $W_f$——crack width, m; $K$——reservoir permeability, md; $h$——effective thickness, m; $R_e$——reservoir radius, m; $r_w$——wellbore radius, m; $r_f$——crack radius, m
Under the guidance of the above formula, the recovery rates of 7 sand bodies with different conductivity under different penetration ratios are simulated and calculated. The results show that the production ratio is higher when the penetration ratio is 0.17 ~ 0.40. From the perspective of input and output, the benefit is higher when the design penetration ratio is 0.17 ~ 0.30. Therefore, it is better to design the penetration ratio above 0.17 for production wells (fig. 3).

Three of the four potential intervals are perforated and completed by current-limiting method. In order to achieve efficient production, it is necessary not only to establish oil-water well connectivity through artificial fractures in the plane to improve the degree of water drive control, but also to finely clamp the intervals in the longitudinal direction to ensure accurate fracturing of the target interval. Therefore, fine control fracturing technology is selected. 3-6 small layers are to be reconstructed in the same section by current-limiting perforation fracturing, and the designed sand quantity is 9-10m³ limited by the material of sand blasting device. The actual implementation effect is shown in figs. 5 and 6. Some relatively well-developed layers reach the reconstruction effect, while the relatively poorly developed layers of oil layers do not reach the ideal effect. The current-limiting fracturing completion has the defects of weak reconstruction purpose and small reconstruction radius. Fine control limit fracturing is firstly refined to 2-3 small layers in the fracturing control interval in the same clamping interval, so that the fracturing target layer is accurately improved; Secondly, by increasing the sand ratio step by step, the single-layer transformation radius is increased to achieve a large penetration ratio, and the injection-production well spacing is reduced for wells that do not establish effective communication, thus achieving the purpose of effective control of reservoir sand bodies.

3.3 Optimization of Target Layer for Reconstruction

In order to accurately find out the residual potential, the distribution characteristics of sedimentary sand bodies in Well H are analyzed by using the results of fine geological research. The main distribution characteristics of sand bodies in this well are sheet-like sheet sand, and some of them are developed at the river channel edge or at the channel deterioration position. According to the
injection-production connectivity and structural characteristics, 11 potential layers 4#, 5#, 6#, 10#, 11#, 12#, 13#, 14#, 20#, 21#, 22# have been determined. As two layers are close to faults, they are not used as the target layer for this transformation temporarily. Due to the limitation of process separation distance, this transformation layer is divided into four sections, of which three sections are treated by fine sand control fracturing technology and the other section by multi-fracture sand control fracturing technology.

| Distribution characteristics of sand body | A Class of Connectivity Relations between Injection and Production | Class II Connectivity between Injection and Production | Three Kinds of Connectivity Relations between Injection and Production | potential | Remarks |
|-----------------------------------------|---------------------------------------------------------------|----------------------------------------------------|---------------------------------------------------------------|-----------|--------|
| Sheet sands                              | 2#, 3#, 7#, 8#, 9#, 16#                                       |                                                    |                                                               | Low       | Potential |
| A sheet of sand with a certain thickness | 4#, 5#                                                       | 20#                                                |                                                               | Low       | Potential |
| Tubular sheet sand                       | 1#                                                          |                                                    |                                                               | Low       | Potential |
| Main Sand Edge, Interface occlusion      | 6#                                                          |                                                    |                                                               | Potential |
| Variation position of river course, Interface occlusion | 10#, 11#, 12#, 13#, 14#                                        |                                                    |                                                               | High      | Potential |
| Riverside                                | 21#, 22#                                                    |                                                    |                                                               | High      | Within 50 meters from the fault |
| Off balance sheet                        | 17#, 18#, 19#, 15#                                          |                                                    |                                                               | Low       | Potential |

3.4 Process Parameter Design

On the basis of the numerical simulation results, the scale design principle of this transformation is to design the fracture length with the sand body interface between injection and production well points and the maximum release of reservoir energy as the control objectives. First, the penetration ratio is controlled to be between 15% and 30%.

Calculation of effective displacement distance between oil and water wells by simulation theory:

\[
\lambda = -0.0225 \log K + 0.0847
\]

\[
L = \frac{P_w - P_t - \frac{c n \mu \eta}{K_h}}{\lambda}
\]

In the formula, Where A-starting pressure gradient, MPa/m; K-permeability, 10\(^3\)μ m\(^2\); L-effective displacement distance, m; PW-Flow Pressure of Water Injection Well, MPa; pw-Flowing Pressure of Oil Production Well, MPa; c-unit conversion factor; n-ratio of row spacing to well spacing; μ-viscosity of underground crude oil, mPa•s; η-stable fluid production strength, μ/(d•m); h-effective thickness, m.

Considering comprehensively the distribution characteristics of sand body, injection-production
well spacing, influence of penetration ratio on recovery ratio and cost, the design fracture length is 50 ~ 68m, the sand ratio is 15 ~ 26%, and sand addition amount of single layer is 35 ~ 65 m³.

In order to solve the problem of large fracturing fluid backflow, the fracturing fluid selects a low-damage and environment-friendly associative fracturing fluid, increases the construction displacement from 3.0 m³/min to 4.5 m³/min to improve the opening probability, and designs a sand fixing agent of 0.8 m³ for each fracture to ensure the sand quantity in the fracture, and further ensures the fracturing effect through multiple measures.

| Layer number | Firing interval/m | thickness | Sandstone/m | effective/m | Fracturing mode | Fracture length/m | Proppant | Fracturing fluid volume/m³ | Construction displacement /m³/min | Gel breaker |
|--------------|------------------|-----------|-------------|-------------|-----------------|-------------------|----------|---------------------------|----------------------------------|-------------|
| 18# ~ 20#   | 1168.9 ~ 1172.8  | 2.8       | 1.1         | Multi-fracture sand control body | 37               | 40               | 1.6         | 280.6                     | 4.5                 | 200         |
| 10# ~ 11#   | 1138.3 ~ 1141.3  | 2.0       | 0.7         | Precision control fracturing    | 50               | 35               | 0.8         | 245.3                     | 4.5                 | 100         |
| 12# ~ 14#   | 1131.2 ~ 1134.0  | 2.1       | /           | Precision control fracturing    | 68               | 65               | 0.8         | 446.1                     | 4.5                 | 100         |
| 20#         | 1099.9 ~ 1100.7  | 1.3       | 0.3         | Precision control fracturing    | 50               | 35               | 0.8         | 245                       | 4.0                 | 100         |
| Total       |                  | 8.2       | 2.1         |             |                 | 205               | 4          | 1217                      | 75                  |             |

4. Application Effect Evaluation
On September 22, 2018, Well H strictly implemented the fine control fracturing plan, and then pumped down for production. The daily fluid production at the initial stage of fracturing was 40.3t, which was 3.6 times that before fracturing. The initial daily oil production was 9.86t, which was 9.16t higher than that before fracturing, the water cut was 75.5%, which was 18.7% lower than that before fracturing, and the cost is recovered after 139 days of operation. It is still effective at present. Up to the time of publication, it has been in operation for 230 days, with a cumulative oil increase of 727t. The test results show that the fine control fracturing technology is a more accurate and efficient potential tapping technology for three types of reservoirs completed by current limiting method.

5. Conclusions
(1) Three types of reservoirs are the indispensable to replace and stabilize oil fields in the future. Fine fracturing technology provides technical means to tap the potential of the three types of reservoirs.

(2) The optimization of fracturing parameters cannot be separated from the understanding of reservoir conditions and the distribution characteristics of residual potential. Fine reservoir description is the basis of all scheme designs.

(3) Compared with the conventional current limiting method, the small number of layers and holes in the corresponding fracturing block are greatly reduced, and the reconstruction horizon is more accurate. However, in order to establish benign communication between injection wells and production wells, long seams need to be made, the sand volume is greatly increased, and the construction cost is increased to a certain extent. In the future, it is still necessary to further optimize the penetration ratio to optimize the template under the corresponding relationship between different oil and water wells, comprehensively consider the input-output ratio, and further reduce the economic
feasibility of fine control fracturing technology.

(4) The fine control fracturing technology has made technological innovation according to the development characteristics of the three types of reservoirs, and has achieved remarkable field application effect. It has explored a new way for stable production in the late stage of ultra-high water cut and can be popularized and applied in similar reservoirs.

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