Practice and Effect of Fine Development in High Water Cut Stage of An Oilfield

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Abstract. In order to improve the development effect of An oil field Oilfield in high water cut stage, the author has adopted the method of fine reservoir characteristics description, fine injection-production system adjustment, fine injection-production structure adjustment and further studied on the reservoir development characteristics and channel sand body sedimentary model, remaining oil type and potential, single sand body tapping potential. The results show that, based on the correct understanding of the characteristics of reservoir sedimentation, using the favorable timing of encryption and carrying out the adjustment of injection and production system to determine methods of improving relationship of injection-production in different types of sand bodies and improve the control degree of water flooding. By studying on injection-production adjustment of different area, Well patterns and sand bodies, the matching adjustment of the two well patterns is realized, and three kinds of planimetric connectivity and longitudinal "345" subdivision boundaries are determined. Using the technology of "five directions" tapping potential and fine development, the oil field decline has been effectively controlled and the development effect has been improved.

1. Introduction
After more than 20 years of water flooding development, An oil field Oilfield has gone through four stages of development, such as elastic mining, water injection development, external expansion and production, and encryption and adjustment. At present, it has entered high water cut period (80.4%). After cyclic waterflooding, polymer flooding, CDG and compound ion depth profile control, contradictions of development are still existing: (1) the development of narrow channels, the high proportion of single well spacing control sand body (66%) and the perfect degree of injection-production is low. (2) The channel sand reservoir is unevenly distributed, which is characterized by serious water flooding at the bottom of the positive rhythm channel sand body, low overall washing ratio (46.2%) and high ratio of medium water washing (72.7%); (3) The reserves is mainly concentrated in the channel sand bodies (19.8%), thin-poor layer has little reserves and poor producing. The result is that the proportion of low-productivity wells is high, so as to long shut-in wells, the old wells have a high rate of natural decline and the oil production rate is low which forms "three high and one low" development characteristics. It is necessary to carry out fine research and practice, and explore new ways to improve oil field development effect in high water cut stage.

2. Reservoir sedimentary characteristics and remaining oil distribution
Based on the fine reservoir description, the remaining oil distribution is comprehensively analyzed to study the producing status and potential of the reservoirs which provides a theoretical basis for later
practice.

2.1 Study on Characteristics of Reservoir sediment

2.1.1 An oil field oil field is controlled by the eastern single water system
The root of the water system develops in the area of some well1-some well2, it has large hydrodynamic energy and 6 secondary water systems from north to south. An oil field is influenced from the second secondary water system to the sixth secondary water system. The main water system develops sandstone, the secondary water system is smaller and the sandstone is thinner. The regional sedimentary is mainly divided into distributary plain surfaces and inner front surfaces sedimentation.

2.1.2 Narrow channel sand development, poor interchannel sand development poor channel vertical inheritance
Narrow channel sand development: near the lake shoreline, shallow lake water body, and weak lake wave diversion of the river channel.
The development of interchannel sand is poor: far from the provenance area, the hydrodynamics is weak, the fine grain sand only deposits in very few big flood period or the partial breach.
The vertical succession of the river is poor: the hydrodynamic force of the river is weak and there is not large-scale deep eroded valley.

2.1.3 Planar distribution and deposition pattern of single sand bodies
Based on the modern sedimentary model and combined with the sand body anatomy of Xingnan dense well pattern, extension law of river is studied. The technology of sandstone phase detection is used to establish reservoir tracking method. Due to the rapid evolution of rapid water-retrogradation--slow water-retrogradation and relative stability-- water-transgression evolution, the sand body along the source direction exhibits a narrow network-broad net-sheet-branch-strip-solitary variation trend of sedimentary model. In the longitudinal direction, the single sand body presents a cross migration and cutting superposition, vertical single superposition and isolated-type. The first two develop in complex channel sand bodies, the last one mainly develops in narrow channel sand bodies.
The single sand body tracing formed a sandwich spreading pattern in deposition units and the single sand layers. The barriers in deposition units distribute stably, average thickness is at high degree up to 3.1m. Physical properties sandwich and calcareous sandwich are often occured in thick reservoir, but their distribution is limited and thickness is less than 0.6m. The distribution of sandwich from sand bodies center to boundaries is erosion surface-physical properties sandwich-shale sandwich, calcareous sandwich layer is located at the top or bottom of the channel and the distribution is random.

2.2 Study on the distribution law of remaining oil
On the basis of fine geological research, through technical means of multidisciplinary research and integrated application of modeling and numerical simulation, coring data, test data (water profile, fluid profile, C / O ratio, casing resistance) and dynamic analysis, the remaining oil analysis program has been programmed to determine distribution of remaining oil overall law.

2.2.1 Plane residual oil scattered distribution in the main
The remaining oil distribution in the plane is divided into three types: contiguous distribution, local flake distribution and scattered patchy type. the residual recoverable reserves of first one is \(32.5 \times 10^4\)t, accounting for 25.8% oftotal residual recoverable reserves; the residual recoverable reserves of local flake distribution accounts for 15.6% the residual recoverable reserves of scattered distribution accounts for 58.6% Which is the main residual oil distribution type in An oil field oilfield.

2.2.2 Residual oil in the longitudinal direction is mainly concentrated in layer22, layer3 and layer6
Nearly 80% of the remaining oil concentrates in channel sand body, the residual recoverable reserves of
the upper sandstone group mainly concentrates in layer I22, layer 3 layer and accounts for 28.1% of total remaining recoverable reserves; the lower sand group residual recoverable reserves concentrates in layer 6 and accounts for 13.2% of total remaining recoverable reserves.

2.2.3 The main types of remaining oil are unilateral injection and imperfect injection-production

After completion of encryption and adjustment in 2009, the well pattern control degree of sand body has been greatly improved. The control degree of water flooding has increased from 70.74% to 78.97%. Under the condition of this well pattern, dynamic monitoring data and dynamic analysis method have been used to analyze the relationship between injection and production of single sand body. There were six types of remaining oil, namely prosodic sandwich type, imperfect injection-production type, plane water absorption difference type, unidirectional water injection type, plane face change output difference type, interlayer interference type.

| Sedimentation unit | Channel sand (%) | Interfluvial sand (%) | Total (%) |
|--------------------|------------------|-----------------------|-----------|
| Layer 21           | 3.5              | 3.5                   | 4.5       | 8        |
| Layer 22           | 0.4              | 0.2                   | 9.8       | 10.4     | 2.4       | 12.8     |
| Layer 3            | 4.5              | 4                     | 3.3       | 11.8     | 3.5       | 15.3     |
| Layer 41           | 0.7              | 0.6                   | 9.1       | 10.4     | 1.8       | 12.2     |
| Layer 42           | 0.5              | 0.3                   | 3.3       | 4.1      | 0.6       | 4.7      |
| Layer 51           | 1.1              | 3.3                   | 4.8       | 9.2      | 2.1       | 11.3     |
| Layer 52           | 0.3              | 1.4                   | 5.4       | 7.1      | 2.7       | 9.8      |
| Layer 6            | 8.1              | 3                     | 0.4       | 11.5     | 1.7       | 13.2     |
| Layer 7            | 1.5              | 2.9                   | 2.8       | 7.2      | 1.4       | 8.6      |
| Layer 8            | 0.5              | 0.4                   | 1.1       | 2        | 0.4       | 2.4      |
| Layer 9            | 0.2              | 0.3                   | 0.4       | 0.9      | 0.8       | 1.7      |
| Total              | 17.8             | 16.4                  | 43.9      | 78.1     | 21.9      | 100      |

There are 1,750 thin layers in 324 oil wells in An oil field Oilfield, among them 515 are potential layers which accounts for 29.4%. The main remaining oil types are unidirectional water injection type and imperfect injection-production type, and the proportion of remaining recoverable reserves to total remaining recoverable reserves is 37.8% and 24.7%.

According to the residual recoverable reserves of remaining oil, the remaining oil types mainly consists of unidirectional water injection type and imperfect injection-production type. The remaining recoverable reserves of these two accounts for 37.8% and 24.7% of the total remaining recoverable reserves.

| Type of residual oil                      | Potential Layer (number) | Layer Percent (%) | Residual Recoverable Reserves (10^4t) | Recoverable Reserves Percent (%) |
|------------------------------------------|--------------------------|-------------------|--------------------------------------|----------------------------------|
| Unidirectional water injection           | 165                      | 9.4               | 74                                   | 37.8                             |
| Plane heterogeneity                      | 105                      | 6                 | 12                                   | 6.2                              |
| Plane difference of water absorptivity   | 45                       | 2.6               | 21                                   | 10.7                             |
| Injection-production incompleten         | 100                      | 5.7               | 48                                   | 24.7                             |
| Rhythmicity                             | 83                       | 4.7               | 38                                   | 19.4                             |
| Interlayer interference                  | 17                       | 1                 | 2                                    | 1.2                              |
| Total                                    | 515                      | 29.4              | 196                                  | 100                              |
3. Fine development practice and effect

Aiming at the main contradictions and potential tapping difficulties of An oil field oilfield in high water cut period, the basic adjustment thought is putting forward to improve the injection - production relationship of single sand body and control the low productive well and long time shut-in wells. On the basis of further understanding of reservoir, two treatment technologies of high water cut period are formed, namely adjustment technology of injection-production system, optimization technology of injection-production structure, and constructing adjustment and development mode of high water cut period.

3.1 fine injection-production system adjustment, improving the degree of reserves control

From injection-production relation of channel sand, the effective thickness of one-way connection and disconnection is 652.0m, the narrow channel effective thickness of one-way connection and disconnection is the largest, up to 416.8m, accounting for 63.9% which is caused by fault cutting and narrow channel impacting. The statistical analysis of control degree of waterflooding of channel sandbodies based on relationship between structural position and well location shows that the control degree of waterflooding of channel sandbodies at the edge of fault is only 72.6%, but in the well pattern is up to 91.4%. It determines that the channel sand body at the edge of the fault should be increased the direction of water injection and reduced proportion of unconnection; the channel sand body in well pattern should be improved proportion of multi-directional connection.

For different types of sand bodies, two kinds of injection modes are mainly adopted: if sand bodies are well connected, the whole sand converted-injection is adopted; if sand bodies are narrow strips, flexible converted-injection is adopted. Since the year of 2009, 25 oil wells have been adopted converted-injection, the control degree of water flooding has increased to 81.02%, the water flood control reserves has increased by 642.4 thousand tons, the thickness of unconnection channel sand has been reduced by 20.6m, and the channel sand control degree of water flooding has increased from 80.74% to 82.34%.

| Well structure       | disconnect (%) | One-way (%) | Two-way (%) | Multiway (%) | total (%)   | Direction of adjustment       |
|----------------------|---------------|------------|------------|-------------|------------|-------------------------------|
| Along fault          | 27.36         | 41.18      | 25.64      | 5.82        | 72.64      | Additional waterflood direction |
| In the well pattern  | 8.59          | 30.35      | 38.32      | 22.75       | 91.41      | Increase multiway proportion   |
| Total                | 19.26         | 36.51      | 31.11      | 13.12       | 80.74      |                               |

3.2 Adjusting fine injection-production structure, improving the plane injection-production difference

The potential of injection-production structure adjustment between blocks, wells and sandbodies is existed by the characteristics of rolling development, the two sets of well patterns and various sand bodies in An oil field oilfield.

3.2.1 Structural adjustment of divisional injection and production

Taking production volume of 5t and 80% of water content as limit, the region is divided into four blocks: low yield-low water content, low yield-high water content, high yield-low water content and high yield-high water content. On the basis of characteristics of development in different regions, governance countermeasures for different regions are made, such as low yield region enhanced pressure control, high yield region enhanced water control.

From 2010 to 2012, divisional injection-production structure has been adjusted since 534 wells times of integrative injection-production adjustment. The ratio of water injection in low yield-low water content region increased from 33.0% to 40.5%, and the production liquid structure increased from 30.0% to 40.4%. The ratio of water injection in high yield-high water content region decreased from 48.8% to 38.6%, and the production liquid structure decreased from 52.1% to 39.3%.
3.2.2 adjustment in different well patterns

An oil field Oilfield has 150 oil and water wells, 74.1% of total water content, 42.1 thousand tons oil per year which accounts for 42.4% of total output, 21.7% of composite decline rate. Thus infill wells adjustment in An oil field oilfield is most important.

For the status quo of high proportion of infill wells output and high declining, balanced injection-production adjustment should be paid more attention and infill wells decline should be further controlled. For injection side, it should strengthen adjustment for infill wells of fault edge type, well center type and expansion type to increase liquid and control water; for production side, through blocking high water layers in low-oil wells and adjust layers to optimize the plane flow direction, improve the injection-production relationship and promote the low permeability layers. In the past three years, 241 infill wells times have been adjusted of which 145 water injection wells times have been adjusted and 65 oil wells times measures have been carried out, the composite decline rate has slowed down from 21.7% to 16.5%, by 5.2 percentage points.

For example, in June 2011, 1-5 layers in well1 were shut plugged and 7-8 layers were taken measure of perforation adding. At the same time the third section of shen62-18 well distributed 5m³/d water. After adjustment, the daily production of oil increased 3.0t, water content cut 60 percentage points.

### Table 4  The subarea treatment measures of the Demonstration

| Subarea                          | Liquid Liquid (t/d) | Total water-cut (%) | Geologic features&cauce analysis                        | Countermeasure                                                                 |
|---------------------------------|--------------------|--------------------|--------------------------------------------------------|------------------------------------------------------------------------------|
| Low-liquid producing& water-cut | 3.5                | 66.4               | The river channel is very narrow.                       | Increase the formation pressure, improve the producing efficiency             |
| Low-liquid producing& high water-cut | 3.8          | 87.7               | The distribution of the sand bodies is scattered       | Increase the formation pressure and control the water injection              |
| High-liquid producing&low water-cut | 5.7            | 14.4               | The interfuvial sand is full-grown.                    | Maintain the producing level and the efficiency                              |
| High-liquid producing&high water-cut | 6.6           | 90                 | The interfuvial sand is joined together and distributed in a large area. | Control the water-injection and protect the producing capacity               |

3.2.3 Adjustment of injection and production structure of sand body

First, the injection side subdivide sthree kinds of connected relations and "345" subdivision water injection boundaries were determined.

I, II, III three types connectivity are subdivided On the plane. Class I connectivity refers to channel sand or main-body sheet sand which is connected with channel sand. Class II connectivity means that main-body sheet sand is connected with main-body sheet sand, and the third type is sand body connected with non-main-body sheet sand.

According to absorption situation of 199 water injection layers, taking water absorption ratio of 80% as standard, fitting the ratio of single sandstone water absorption with number of oil layers in single section, the coefficient of variation of permeability, the thickness of single sandstone (correlation: 93%, 88%, 92%), and the boundary of subdivision water injection is determined: the number of oil layers in single section is less than or equal to 3, the coefficient of variation of permeability is less than 0.4 and the thickness of single sandstone is less than or equal to 5m. According to the subdivision adjustment boundary, combining with reservoir development, interlayer and water injection technology, 48 subdivision potential wells were determined, 40 have been subdivided and the number of subdivided layers was 2.8 which increases 3.6 percentage points.

The second is to develop a single sand body "five directions" technology to tapping potential
According to different types of remaining oil, combining with the size and characteristics of sand bodies, it established five main tapping potential directions and the main technical means.

Directional tapping of high water wells
It excavates remaining oil of fault’s edge by hydraulic jet and ultra-short radius technologies, seven wells have been done, single well increases 1.7t oil per day. For example, well2 which was high water content wells produced 0.4 ton oil per day and its integrated water content was 81.0%. The result of residual oil study shows that the well production is increased by 1.2t and the comprehensive water content cut down to 66.7% because of one-way water injection and the remaining oil enrich area deviated from the direction of water injection.

Expanded tapping potential at the bottom of the same layer
The oil and water identification plates are used to review potential of same layer of oil and water in old wells, the same layers at the bottom of the high water content and low production wells are taken measure as perforation adding and 6 wells times have been done. Such as 8-9 layer of well3, its spontaneous potential is -68mv, 4 meters apparent resistivity is 17Ω·m, falls in the same layer area of the oil-water layer identification map, it have been done perforation adding and upper production layers of layer1-5 were plugged which improves initial daily oil by 2.1 tons and controls water content to 83.4%.

Sand body edge tapping potential
It mainly uses the adjusted technology of encryption and drills the infill well at the sand body edge to raise the well net control degree. This tapping potential method requires the application of fine reservoir description technology to meticulously depict sand body scale and effectively avoid reservoir drilling loss.

Interior within thick layer tapping potential
Closed coring well and dynamic monitoring data show that internal waterflooding of thick layer is uneven and remaining oil is generally concentrated in the upper part of the thick layer or permeability variation due to the vertical and plane heterogeneity. Basing on application of long tube and perforation sealing technology, it blocks the high water content layer with using stable interlayers or small sandwich layers within thick layer, and seven wells have been done and single well increases 1.2t oil. Taking well4 as an example, casing resistivity logging results show water flooding of 7-8 layers are uneven, it increased initial 2.9t oil per day with in-layer water shutoff by small interlayer in upper part of layer.

The dominant facies tapping potential
The dominant reservoirs which are connected with thin-poor reservoirs are fractured to play dominant reservoirs potential. A total of 14 wells were implemented, and the oil production increased by 1.5t per day. Such as well5, because of low-pressure and low-yield, it shut down after commission, and then it increased 3.0t oil per day and the water well profile was improved by taking the measure.

Through single sand body anatomy, relying on the combination of conventional technology, strengthening the application of new technologies, 158 wells have been adjusted, so as to 129 low-production wells and long time shut-in wells, and single well increases 1.2t oil per day. When oil price is 70 $ / bbl, the input-output ratio is 1:2.6.

| Table 5 Directions and technical means in different types of sand |
|---------------------------------|------------------|-----------------|-----------------|------------------------------|------------------|
| types of sand                   | Total layers     | Proportion (%)  | single effective thickness (m) | Residual recoverable reserves (10^4t) | Dynamic description | Adjustment direction | Presenr technical |
| Narrow Channel Sand             | 359              | 20.5            | 1.8                           | 109                          | Plane difference between injection and production; high water content | ① plane direction residual oil; ② bottom of the same layer | Hydraulic jet reperforation |
3.3 fine development overall effect analysis
The research and practice of An oil field oilfield fine development in high water cut period have remarkable effect. The water injection in oil layers is more fine, the separate injection ratio increases from 83.5% to 87.1%, the producing sand ratio increases from 75.1% to 87.1%, the natural decline and comprehensive decline of the old wells are decreased by 3.91 and 6.96 percentage points respectively, the old wells comprehensive decline are 8.64% under 10% control target, It enhances the recovery rate of 1.22 percentage points because of increasing 225,400 tons recoverable reserves.

4. Conclusion
(1) As the oil field enters the stage of high water cut period, it is necessary to identify and classify the single sand body based on the sand layer of sedimentary unit because the fine reservoir description of simple thick sand layer can not meet the demand of remaining oil tapping potential.
(2) The fine reservoir description depicts the sedimentary characteristics of the narrow sand body, and a single sand body sedimentary formation model is established. The An oil field oil field is controlled by the single water system in the eastern part It has experienced sedimentary evolution of rapid water-retrogradation--slow water-retrogradation and relative stability-- water-transgression, which leads to the development of narrow channel sand, non-development of channel sand and vertical succession of river channel.
(3) Nearly 80% of remaining oil in An oil field Oilfield is concentrated in channel sand bodies. There are mainly six types of remaining oil in the present well pattern, among them one-way water injection type and imperfect injection-production type are most common.
(4) Injection-production system adjustment is the basis of fine development. Focusing on the favorable timing of encryption and injection-production system adjustment, carrying out the the whole converted-injection and flexible converted-injection, and increasing the water injection directions at the edge of faults and the multi-directional connectivity ratio were the main methods to effectively improve the reserve control degree and provide material basis for the following adjustment.
(5) Injection-production structure adjustment is the core of fine development. Based on perfecting the injection-production relationship of single sand body and focusing on the treatment of low-production wells and long time shut-in wells, the adjustment method of injection-production structure of different parts, different well patterns and different sand bodies are studied. The practice shows that the fine control development goal for reducing oilfield decline less than 10% is achieved, and the oil field development effect is improved.

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