Fine study on single sand body and measures for tapping the potential of residual oil during polymer flooding in Pubei reservoir of Daqing

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Abstract. In order to effectively guide the narrow channel sand body oil fields to exploit, according to the sand body distribution characteristics and geological genesis of narrow channel sand body oil fields, the type of single sand body is clarified. By means of identification of logging curves and correlation of well-tie profile, the internal structure of single sand body is recognized. and then the remaining oil genesis, distribution characteristics and the potential areas for polymer flooding are clarified by combining numerical simulation technology and dynamic analysis technology, and the remaining oil potential tapping method is designed by taking into consideration various factors including the characteristics of the remaining oil, reservoir property and product dynamic character. The result shows that the single sand body is divided into five types including multiphase channel superposition, distributary channel, single channel, sheet sand and lenticular sand. Potential remaining oil mainly are distributed in thick oil layers of multiphase channel superposition type and distributary channel type in which channel sands were developed and sedimentary environment are stable inner front facies and lake regressive inner front facies. The remaining oil is developed by optimizing the parameters of polymer flooding and combining many different measures. The study provides technical support for the efficient exploration for polymer flooding.

1. Introduction

The earlier study on the single sand body is only based on the sedimentary microfacies and sand body spatial distribution features, while the study of the internal structure feature of single sand body is neglected. In recent years, along with the continuous development of fine reservoir description technique, the sand body description continually becomes fine; the depicting of internal structure feature of single sand body gradually becomes perfect. In 1985 Miall proposed a analytical method of architectural-elements used for fluvial deposition[1], and in 1988 he published the research contents of architectural-elements and interface about fluvial deposition[2].

Based on Miall’s studies and sedimentary cycle characteristics of the single sand body and interlayer distribution, domestic scholars did a large number of researches about fluvial depositional interface for different sedimentary settings. In 2000 Ma Shizhong et al. established horizontal and
vertical sedimentary patterns of single lateral accretion body of meandering point bar and studied its three-dimensional configuration and interface on the basis of datum such as vertical sequences of point bar or lateral accretion body type of Daqing placanticline[3]. Then aiming at Daqing Oilfield, they used the sealed coring datum and the logging response characteristics, studied the internal structure of underwater distributary channel that belongs to Songliao basin of large fluvial-delta sedimentary System, and established internal structure of channel sand body and vertical sequence interface order[4]. With the deepening study of internal structure model of single sand body, much attention has been paid to the effect of the interlayer distribution on remaining oil distribution [5-7]. In recent years, the relevant studies are getting more and more perfect, and have been well applied in many blocks.

In this paper the research area is located in Putaohua oilfield, which is in the southern of Daqing Placanticline, and belongs to delta front subfacies depositional system which is controlled by the northern provenance. The channel sedimentary sand orientation is from north to south, with sheet, zebraic, interrupted zebraic or lens-shaped distributions, and it is characterized by thin, narrow and relatively large lateral variation. Many adjustments of well pattern thickening and injection-production system have done since the area being developed. But now the area has entered extra high water cut period and the remaining oil becomes so scattered that there is much more difficulty for tapping the potential of remaining oil. In order to seek out a new way to tapping the potential of remaining oil and enhance recovery by well pattern thickening and polymer flooding, a test area of polymer flooding has been carried out. Because the area is a reservoir with medium-low permeability and thin-narrow sand body, it’s necessary that the fine study on the internal structural feature of single sand body and the precise description of remaining oil distribution should be done, and then make a advisable method of remaining oil potential tapping to ensure the development effect of polymer flooding.

2. Identification and classification of single sand body
Single sand body is a sand unit, relative independent on development but genetically related on geological formation. From deposition perspective, single sand body has the same cause that is vertical sequential deposition or superimposed erosion [8-9]. According to sedimentary characteristics of the area and definition of single sand body, the sand body assemblages that are continuous in vertical and in plane itself but discontinuous with upper and lower sand body will be recognized as a single sand body[10-12].

Combined with block sand body sedimentary background and characteristics, the single sand body is divided into five types: multiphase channel superposition, distributary channel, single channel, sheet sand and lenticular sand.

Multiphase channel superposition single sand body consists of distributary main channel, underwater distributary channel and shallow shoal underwater distributary, among them, mainly is the underwater distributary main channel; distributary channel single sand consists of distributary main channel, underwater distributary channel and shallow shoal underwater distributary, among them, mainly is distributary main channel and distributary shallow river; Single channel single sand body consists of inside the leading edge of the river, transitional channel and non- body sheet sand body; sheeted sand monosandbody substantially consists of body and non-body sheet sand; lenticular mould single sand is of isolated lenticular distribution.

3. Internal structure characteristics of single sand bodies
Reference to Maill’s analysis method of structural element and the internal structure of channel and interface classes vertical sequence Proposed by Ma Shizhong. And according to the internal structure interface division of the core data from the two sealed coring wells near experimental zone to demarcate experimental zone’s logging curve interface, to carry out the analysis of the internal structure of the single sand body. Pu 68-Jian 862 well’s core internal structure analysis diagram is shown in figure 1. The wash surface A can be seen at the bottom of the figure. The microelectrode curve increases abruptly at the interface, which is level 4. The calcareous siltstone developed at the top. And the peaked microelectrode curve shows characteristics of high amplitude and huge difference.
The physical interlayer B developed at the middle of sand layer. Microelectrode curve and spontaneous potential curve amplitude decrease, which shows the interface is level 3. According to the structure interface of core data demarcate logging curve (Figure 2) and the interfaces of level 3 to level 5 can be identified on the logging curve. And the interface of level 5 is equal to boundary of sandstone series or thin layers. A stable thick mudstone generally develops at the interface; the interface of level 4 is equal to boundary of sedimentary units, interlayers mostly developed at interface, which are mainly composed of argillaceous interlayer and there are also a few physical interlayer and calcareous interlayer; the interface of level 3 is equal to boundary of uniphase channel. What develop at the interface mostly are physical property interlayers, and argillaceous interlayer and calcium sandwich are less; and interface of level 1 and 2 represent the level interface of stratification, which cannot be identified and contrasted laterally on the well logging curve.

![Core internal structure analysis of 7P68 coring Well](image1)

![Single sand body level interface](image2)

On the basis of sedimentary cycle and interlayer distribution, the internal structure of reservoir is recognized subtly by means of the logging curves and correlation of well-tie profile. The result shows that channel’s width of channel type single sand body’s single genetic structure is narrow and most of width is less than a well spacing. The degree of channel’s curvature is little, dominated by low sinuosity and straight channels. Then, internal channel of the multiphase channel superposition type single sand body is given priority to the multiphase channel superposition in the vertical. And the channel positions developed in different stages are unstable. They are superimposed on a plane and present cross mesh, schistose, dendritic locally. Physical property interlayer and argillaceous interlayer developed at vertical dismembered superimposed location, the average frequency of interlayers is 0.19/m; the internal sedimentation time of distributary channel type single sand body is relatively few and the channel positions developed in different stages are relatively stable. The channel branches or intersections are dendritic on the plane. The scope of interlayers is smaller and average frequency of interlayers is 0.18/m; the channel positions of single channel type single sand body that developed in different stages are stable. Migration swing is small. Channels are superposed and banded mostly. The scope of interlayers is smaller and average frequency of interlayers is 0.11/m; the channel positions of sheet sand type single sand body that developed in different stages are smaller, which are zebraic on the plane, one-period sheet sand body distribution of irregular thin bedded sheet structure, interlayer is given priority to argillaceous interlayer, followed by physical interlayer and average frequency of interlayer is 0.14/m (Figure 3).
Figure 3. The reservoir section of single sand body formation

4. Remaining oil distribution characteristics of single sand body

4.1. Types of remaining oil

By using numerical simulation technique to accurately describe the remaining oil distribution, and according to the genesis of remaining oil [14], we classified remaining oil into 3 categories: on the top of thick oil layer type, reservoir injection-production faultiness type, poor reservoir type (Figure 4). Among them, the type of remaining oil on the top of thick oil layer’s sand body are main channel sand body that effective thickness mostly over 1.0m. Entirety development is stable, connected situation is
good, injection-production relation is perfect, in-layer heterogeneity are mainly positive rhythm and compound positive rhythm, this type of remaining oil is major target of polymer flooding potential tapping; the type of reservoir injection-production faultiness mainly because of the small sand body’s development scale, narrow band, and connected direction is single or formed without connection, this type of remaining oil can be target of polymer flooding potential tapping selectively; remaining oil of the poor reservoir type mainly because of the thin reservoir and poor physical property, it has two types: one is the thin and poor reservoir which has large distributions area, the other is on edge sand body’s poor physical property part, this kind of remaining oil mainly distributed in sand sheet’s sand body, can be the major target of water flooding after polymer flooding potential tapping.

Figure 4. (a) top of thick oil layer type

Figure 4. (b) reservoir injection-production aultiness type

Figure 4. (c) poor reservoir type

Figure 4. The remaining oil type of single sand bodies.
4.2. Types of remaining oil

By using numerical simulation technique to analyze remaining oil distribution of different kinds of single sand body [13-14], the results show (Table 1) that remaining oil mainly distributed in multiphase channel superposition, distributary channel and sheet sand. From the type of single sand body, remaining oil mainly concentrate on multiphase channel superposition and distributary channel’s single sand body that developed channel sand. Sedimentary environment are stable inner front facies and lake regressive inner front facies, is the major target of polymer flooding potential tapping. From different types of remaining oil, thick oil layer take the most percentage of remaining oil reserve, most is thick-injection and thick-production, cover 71.7% of remaining oil reserve, so the thick-injection and thick-production layer is the major layer; and the kind of reservoir injection-production faultiness’s remaining oil reserve mainly is unidirectional response, cover 8.3% of remaining oil reserve; the kind of poor layer’s remaining oil reserve narrow distributed, only cover 6.7% of total remaining oil reserve.

On the basis of numerical simulation’s result, combine with the information of two sealing core drilling well in Pubei oilfield, analyze single sand body internal structure’s control action to remaining oil (Figure 5), the results show that level 4 interface control channel sand’s whole remaining oil distribution, bottom water flushed is serious, remaining oil concentrate in the middle-upper part; if level 3 interface develop argillaceous interlayer (or calcareous interlayer)[15], remaining oil of interlayer upper-lower part structure mainly concentrate in the upper part of each structure, show that remaining oil in the same sand body concentrated piecewise, if develop physical property interlayer or nondeveloped interlayer, the control degree of interface to remaining oil is poor or has no effect, remaining oil in interface upper structure is more concentrated.

| Sand body type            | permeability (10\(^2\)μm\(^2\)) | degree of reserve recovery (%) | Thick injection and thick production | Thin injection and thick production | injection-production faultiness | Poor layer | total |
|--------------------------|----------------------------------|--------------------------------|-------------------------------------|-----------------------------------|---------------------------------|------------|-------|
| multiphase channel       | 310.1                            | 38.85                          | 19.8                                | 1.1                               | 1.6                             | 0.4        | 0.5   | 1.1 | 24.4 |
| superposition            |                                  |                                |                                     |                                   |                                 |            |       |     |      |
| distributary channel     | 335.3                            | 37.04                          | 26.2                                | 2.1                               | 2.5                             | 0.7        | 0.5   | 1.2 | 33.2 |
| sheet sand               | 223.5                            | 30.64                          | 18.9                                | 3.5                               | 1.3                             | 0.5        | 0.5   | 3.1 | 28.0 |
| single channel           | 260.9                            | 31.39                          | 6.1                                 | 0.0                               | 1.9                             | 0.8        | 0.4   | 0.8 | 10.0 |
| lenticular sand          | 132.6                            | 14.41                          | 0.8                                 | 0.0                               | 1.0                             | 1.2        | 1.1   | 0.4 | 4.4  |
| total                    | 284.3                            | 34.52                          | 71.7                                | 6.7                               | 8.3                             | 3.6        | 3.0   | 6.7 | 100.0 |

5. The method of remaining oil potential tapping for single sand body

Single sand body seen as a unit, advisable method of remaining oil potential tapping is made for distinct type of remaining oil by considering the inner structural feature of single sand body, the
connecting relationship of sand body between injection well and production wells, the distribution feature of remaining oil, and production situation of wells.

5.1. Remaining oil of the top type of thick reservoir
This type remaining oil falls into two subclasses, thick-layer injection with thick-layer production and thick-layer injection with thin-layer production. In the concentrated area of remaining oil of thick-layer injection with thick-layer production, based on injection-production balance rule, production wells of polymer flooding parameters are optimized. On the premise of feasible injection pressure, the injection rate should be promoted in well field of low injection rate. Injection concentration should be regulated firstly in well field of high injection rate, in order to guarantee equilibrium driving of injection and unhurried-smooth ascension of injection pressure. At the same time, in view of response producer in different step, flowing pressure should be reasonably controlled. Then measure of augmented injection and raise liquid could be developed for production well. Remaining oil can be sufficiently tapped and polymer flooding effect could be broadened. As to remaining oil of thick-layer injection with thin-layer production, the thin and poor reservoir of injection side causes poor producing degree and the concentrated remaining oil staying in the reservoir of production side. Combining with production performance situation of reservoir of full well and sidetrack drilling of horizontal hole on the injection side reservoir, imbibs situation of thin-poor reservoir could be improved. Fracturing measure achieves synchronous tapping of injection-production wells. Based on above redeveloping measures, nine well groups of injection-production wells have been regulated after polymer injection test. The regulation wells of parameter optimization of injection wells are 21 and the regulation wells of fracture of injection wells are 2. The regulation wells of parameter optimization of production wells are 29. The regulation effect is visible. The average daily oil production of 9 well groups is 1.6 tons more than water flooding, and the water cut descents 7.2%. Moreover, by means of comprehensive analysis, it obtains that 16 wells are fit for fracturing in this type of remaining oil. And 4 wells present latent capacity of sidetrack drilling. The control reserve of latent capacity wells is $11.67 \times 10^4$ t. There is a huge potential for further development.

5.2. Remaining oil of imperfect injection-production relationship type
In order to carry out polymer flooding test, the well pattern is encrypted and injection/production relationship is regulated. But due to the narrow channel development, the partly zebraic is more obvious after regulation well pattern and the development breadth of channel is less than 150m. That causes imperfect injection/production relationship of partly well pattern. During polymer flooding, the main potential target is unidirectional response type of remaining oil, by means of regulation of injection/production parameter optimization, augmented injection and liquid extraction. Since the test of polymer flooding carried out, the regulation wells of parameter optimization regulation for edge injection/production wells are 32. The regulation wells of acidulation for injection well are 2. Daily augmented injection is $30m^3$ and submergence depth is about 450m. The average production fluid of single production well is 6.3 tons less than water flooding. The average production oil of single production well is 0.9 tons more than water flooding and water cut is 3.8% less. By means of analysis, there are 6 production wells with fracture potential. There are 2 injection wells with acidulation potential and 1 well with fracture potential. That supplies foundation for efficient tapping during polymer flooding.

5.3. Remaining oil of poor reservoir type
Seen from injection/production relationship, this type of remaining oil falls into two subclasses, thin-layer injection with thin-layer production and thick-layer injection with thin-layer production. The regulation potential of remaining oil of poor reservoir type is low. And this type can not be the main tapped target during polymer flooding. But some individually potential layers could be synchronously reformed and tapped with the main layers, in combination with production situation, enrichment situation of remaining oil and connection situation.
6. Conclusions

- According to the characteristics of single sand body distribution, the single sand body is divided into five types including multiphase channel superposition, distributary channel, single channel, sheet sand and lenticular sand. Channel single sand body which genesis structure body channel is small, bending is little, mainly is low sinuosity and straight channel. The interlayer at the interface mainly is the material and the clay. Single sheet sand body’s single causes structure distribution of irregular thin sheet shape, interlayer mainly is argillaceous interlayer.

- Remaining oil mainly is distributed in thick oil layers of multiphase channel superposition type, distributary channel type and sheet sand type. The main potential of polymer flooding is distributed in, multiphase channel superposition type and distributary channel type which developed channel sand. The type of remaining oil is dominated by the top of thick oil layer, followed by the imperfect injection production relationship. From the perspective of the internal structure, the interlayer of the interface has a certain effect on the distribution of the remaining oil. The control degree of the remaining oil in the internal structure is higher than that of the material layer, which is more than the thickness of the calcareous interlayer.

- The main potential layer for polymer flooding are distributed in completeness injection production relationship of thick oil layers and better reservoir properties of unidirectional effect sand body. According to the types of sand body can take note the optimization and adjustment of production parameters, injection production well acidizing and fracturing and increasing injection measures. In view of this type of sand body can adopt injection production parameter optimization adjustment, injection production well acidification and fracturing and other injection measures to achieve the injection production synchronization potential, to ensure that the injection agent balance. For the poor thin layer of remaining oil in the layer can specifically tapping the potential with the main synchronization measures.

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