Investigation on Washing Condition of Reservoir in Region A

Zhao Yuying
No.1 Oil Production Company of Daqing Oilfield Company Ltd., Geological team of 1st. Oil Production plant, Saltu district Daqing city, Heilongjiang province, 163001, China
54434345@qq.com

Abstract-At present, A oilfield is in the extremely high water-cut period, and it is the key to realize the distribution of residual oil potential. Through the data analysis of the sealed coring well, this is one of the most intuitive and reliable methods for residual oil distribution. The changes and growth of water wash thickness of various oil layers can be understood and analyzed, and the evolution process of oil formation status can be clearly seen with the deepening of oilfield water injection development and the infilling and adjustment of well pattern. The results show that the area is in the condition of medium water washing and still has great potential. The washing degree of one kind of oil layer is high, mainly medium and strong washing. The weak and unwashed oil layers are mainly concentrated in the second and third oil layers, which are the target of the next adjustment and exploration. According to the distribution of residual oil in the second and third oil layers, the next step is to optimize the adjustment of injection-production well pattern and the modification of cooperation measures. For improving the level of weak and unwashed reservoirs, it is of guiding significance for the subsequent development of reservoirs in the ultra-high water-cut period.

1. Introduction
Region A has entered the stage of ultra-high water cut development, and the distribution of remaining oil is highly scattered and complex. The key to oilfield development and adjustment in this stage is to further understand, find and develop the potential of remaining oil. The research methods of remaining oil mainly include closed coring well analysis method, development seismic method, water flooded layer logging interpretation method, reservoir numerical simulation method and reservoir engineering method. Compared with other methods, the closed core well analysis method has two main advantages: ① it can accurately reflect the lithology, physical properties and oil content of the underground reservoir, and can directly and intuitively point out the total amount and distribution characteristics of the remaining oil. ② it can get the distribution results of the remaining oil in different types of reservoirs, so as to determine the target reservoir type for the next step of tapping the potential remaining oil.

Since the development in 1966, 42 sealed coring wells have been drilled, which provides a reliable basis for the analysis of oilfield development effect and the deployment of comprehensive adjustment measures. In terms of distribution, it is divided into four regions, mainly concentrated in the first and fourth regions, accounting for the proportion of the whole region 40.47% (Figure 1).
2. **The washing situation of reservoir**

According to different thickness of sandstone, determine reservoir for category class I, class II and class III. The sandstone thickness of class I is larger than 2 m. The sandstone thickness of Class II is between 0.5 m to 2 m, and the thickness of class III is less than 0.5 m. Based on the statistics of different thickness of breakthrough time, the breakthrough of class I reservoir is 40% in the early stage of production. The breakthrough layer has been 100 % since 1990. The producing degree of class II and class III reservoir is poor in the initial stage of development, and the contradiction in all kinds of oil layer are prominent. The gap between the later stage and class I reservoir has become smaller.

3. **Current flooding situations**

Due to the long production time of region A, the breakthrough of the whole situation has far not on behalf of the current breakthrough. The breakthrough of 17 coring wells since 2000 is analyzed. From the classification of reservoir thickness, the ratio without breakthrough of the whole region is 12.74 %, in which class I reservoir is 2.08 %, class II is 4.15 %, and class III is as high as 22.36 %. From the perspective of sub regions, the proportion of no water in zone 1 is 11.76% that in zone 2 is 11.54%, that in zone 3 is 14.08%, and that in zone 4 is 13.19%. The ratio without breakthrough of zone 3 and zone 4 is higher than the entire district, which has exploration potential.
Table 1  Analysis of classified layers breakthrough in region A

| Zone | Classification | All layers | Breakthrough layer | Ratio of breakthrough layer(%) | Ratio of no breakthrough layer(%) |
|------|---------------|------------|-------------------|-------------------------------|---------------------------------|
| 1.   | 1.            | 25.        | 30.               | 90.15%                        | 3.81%                           |
|      | E.            | 14.        | 139.              | 95.89%                        | 4.11%                           |
|      | III.          | 142.       | 111.              | 77.62%                        | 22.28%                          |
|      | subtotal      | 240.       | 198.              | 59.24%                        | 40.76%                          |
| 2.   | 1.            | 10.        | 19.               | 100.00%                       | 0.00%                           |
|      | E.            | 22.        | 2.                | 60.61%                        | 39.39%                          |
|      | III.          | 20.        | 18.               | 80.00%                        | 20.00%                          |
|      | subtotal      | 52.        | 45.               | 88.68%                        | 11.32%                          |
| 3.   | 1.            | 10.        | 19.               | 100.00%                       | 0.00%                           |
|      | E.            | 78.        | 75.               | 66.15%                        | 33.85%                          |
|      | III.          | 116.       | 80.               | 78.72%                        | 21.28%                          |
|      | subtotal      | 213.       | 193.              | 85.62%                        | 14.38%                          |
| 4.   | 1.            | 15.        | 15.               | 100.00%                       | 0.00%                           |
|      | E.            | 92.        | 89.               | 98.74%                        | 1.26%                           |
|      | III.          | 128.       | 100.              | 78.13%                        | 21.87%                          |
|      | subtotal      | 231.       | 204.              | 86.81%                        | 13.19%                          |
| total.| 1.            | 66.        | 64.               | 97.62%                        | 2.38%                           |
|      | E.            | 337.       | 325.              | 95.85%                        | 4.15%                           |
|      | III.          | 497.       | 416.              | 77.04%                        | 22.96%                          |
|      | subtotal      | 840.       | 746.              | 87.26%                        | 12.74%                          |

4. Potential and distribution characteristics of no flushed interval

4.1. Ratio of no flushed thickness
The no flushed thickness ratio of region A is 24%, which no flushed thickness ratio of flushed interval is 19.32 %, and the thickness of no flushed interval is 4.7%. From the classification of reservoir thickness, no flushed thickness ratio in breakthrough interval of class II reservoir is a bit higher (23.31%), and the ratio of class III reservoir is low (12.09%). No flushed thickness ratio in no water breakthrough interval of class III is 20.81 % (table 2).

Table 2  Distribution of no flushed layer in region A

| Sandstone classification | No flushed in breakthrough layer | No flushed in no breakthrough layer | Total |
|-------------------------|---------------------------------|------------------------------------|-------|
|                         | Ratio of effective thickness(%) | Ratio of no flushed thickness(%)  | Ratio of no flushed thickness(%) | Total thickness(m) | Ratio of no flushed thickness(%) | Ratio of no flushed thickness(%) |
| I°                      | 18.56                          | 93.22                             | 79.67                          | 19.92             | 41.92                        |
| II°                     | 23.31                          | 88.66                             | 9.34                           | 73.26             | 26.34                        |
| III°                    | 12.06                          | 36.74                             | 20.81                          | 37.15             | 32.96                        |
| total                   | 19.32                          | 80.42                             | 4.7                             | 190.02            | 24.00                        |

4.2. Potential distribution of no flushed layer
(1) The potential of no flushed layer is mainly distributed in breakthrough interval, accounting for 80.42% of total no flushed thickness ratio.

In zone A, most remaining oil without flushed distribute in breakthrough interval, accounting for 80.42% of total no flushed thickness ratio, no flushed in all layers account for only 19.58 % (table 3).

(2) The potential of no flushed layer is mainly distributed in class I and class II reservoir, accounting for 80.4% of the total no flushed thickness ratio.

From the distribution of no flushed potential in all kinds of reservoir, the no flushed thickness ratio of class I reservoir is 41.9 %, and that of class II r is 38.5%.

(3) The potential of no flushed layer is mainly distributed in No.2, No.4and No.6reservoir group.

From the distribution of no flushed potential in all kinds of layers, 2 and 6 reservoir groups have a higher percentage, respectively for 26.71% and 27.8%. The ratio of No.4 layer is 13.91 % (table 3).
Table 4 Statistical table of washing strength in region A

4.3. The contrast of no flushed condition in all kinds of reservoir
According to the comparison of the thickness of various layers, the no flushed thickness of thick layer is less than that of poor and thin layer, and the produced degree of thin layer is poor. Compare the no flushed thickness of various reservoir, the produced degree of No.1 and No.6 layer is poor, and the ratio of no flushed thickness of thick layer is 42.88% and 28.97%. The use of 3 and 4 reservoir groups are the best, the ratio of no flushed thickness is 18.64 % and 15.5%.

5. Analysis on the degree and potential in washing layers

5.1. Analysis of washing strength in washing layers
In region A, the thickness ratio of strong water washing is 28.97%, that of medium water washing is 55.85%, and that of weak water washing is 15.19%.

According to the reservoir classification (Table 5), the thickness of the reservoir changes from thick to thin, the thickness of strong washing gradually weakens, the thickness of medium washing has little difference, and the thickness of weak washing gradually increases. The washing thickness ratio of class I reservoir is 80.15%, and the oil displacement efficiency is 45.21%. The strong washing ratio is higher(30.73%). The washing thickness ratio of class II reservoir is 71.13%, and the oil displacement efficiency is 46.85%. The washing thickness ratio of class III reservoir is 65.71%, and the oil displacement efficiency is 45.11% (Table 4).

5.2. Analysis of remaining oil potential

5.2.1. Potential analysis of strong washing layer
The strong washing layer is defined as the layer with displacement efficiency larger than 55%, accounting for 20.75% of the total effective thickness, and the average displacement efficiency of this part is 63.13%. The thickness less than the average displacement efficiency of the strong wash layer
accounts for the total strong wash thickness 52.74%, the average oil saturation is 29.6%, lower than the residual oil saturation obtained from the relative permeability curve 29.8%; thickness less than residual oil saturation 62.49%, the average oil saturation is 23.8%.

The displacement efficiency is basically higher than the average displacement efficiency, which shows that nearly 63% of the thickness of strong wash layer has no movable remaining oil potential, which belongs to the large pore channel of invalid circulation.

5.2.2. Potential analysis of medium and weak washing layer

The medium washing layer is defined as the layer with displacement efficiency between 36-55%, accounting for 40.45% of the total effective thickness. The average displacement efficiency of this part is 43.57%, and the average saturation is 40.97%. The thickness less than the average displacement efficiency of medium washing layer accounts for 48.2%, and the average oil saturation is 44.8%. The thickness larger than the average oil saturation of medium washing layer accounts for 64.28%, and the thickness less than the residual oil saturation accounts for 2.6%. It shows that the potential of medium washing layer is larger.

The weak washing layer is defined as the layer with displacement efficiency less than 35%, accounting for 10.65% of the total effective thickness. The average displacement efficiency of this part is 29.4%, and the average saturation is 53.59%. The thickness less than the average displacement efficiency of weak washing layer accounts for 37.14%, and the average oil saturation is 58.1%. The thickness larger than the average oil saturation of weak washing layer accounts for 65.39%. The oil saturation of all weakly washed reservoirs is greater than the residual oil saturation, which has great potential. The average oil saturation of unwashed layer is 63.29%, which is lower than the average oil saturation of washing layer (Table 5).

| Washing degree | Displacement efficiency (%) | Porosity (%) | Initial oil saturation (%) | Current oil saturation (%) |
|----------------|-----------------------------|--------------|---------------------------|--------------------------|
| strong         | 63.13<sup>o</sup>           | 26.55<sup>o</sup> | 72.02<sup>o</sup>         | 26.56<sup>o</sup>        |
| medium         | 43.57<sup>o</sup>           | 28.12<sup>o</sup> | 72.61<sup>o</sup>         | 40.97<sup>o</sup>        |
| weak           | 29.4<sup>o</sup>            | 28.72<sup>o</sup> | 75.9<sup>o</sup>          | 53.59<sup>o</sup>        |
| none           | 0<sup>o</sup>               | 27.81<sup>o</sup> | 63.29<sup>o</sup>         | 63.29<sup>o</sup>        |
| total          | 45.37<sup>o</sup>           | 27.8<sup>o</sup>  | 70.95<sup>o</sup>         | 46.1<sup>o</sup>         |

5.2.3. Comparison of remaining oil potential with various washing degree

Displacement efficiency is an index to describe the production status of the reservoir, while oil saturation is an index to describe the remaining oil in the reservoir. According to the change range of oil saturation of various layers, the oil saturation limit is determined, that is, the oil saturation less than 30% is residual oil, the oil saturation between 31 - 40% is low saturation residual oil, the oil saturation between 41-50% is medium saturation residual oil, and the oil saturation larger than 50% is high saturation residual oil. According to this standard, the potential of remaining oil with different washing degree is given.

According to the analysis, there is a certain potential in the washing layer of region A. The potential to improve the displacement efficiency is 57.07%. The potential of the three categories is 18.43%, 24.72%, and 13.92%. At the same time, Region A has a potential to expand the swept volume, with a value of 27.92 % (24.54% for category I, 2.49% for category II and 0.89% for category III).
6. Conclusions
A. According to the data statistics of coring wells in A Oilfield, the producing degree of all kinds of reservoir conditions (no flushed and flushed) and residual oil distribution are analyzed. The breakthrough ratio of class I reservoir have all been 100%, class II is only 4.15%, the no breakthrough ratio of class III reservoir is 22.36 %. No flushed thickness ratio is 24% of the total thickness, which no breakthrough is 4.7% and breakthrough is 19.3%. The potential mainly exists in the breakthrough interval.

B. Comparing the no flushed conditions of various kinds reservoir, potential mainly exist in class I and class II reservoir. For no flushed condition of reservoir groups. The ratio of 2 and 6 reservoir group have a higher percentage, respectively 26.71 % and 27.8%. The ratio of 4 reservoir group is 13.91%.

C. In the flushed reservoir of oilfield, the ratio of strong flushed thickness is 28.97%, the medium flushed thickness ratio is 55.85 % and the weak flushed thickness ratio is 15.19%. The strong flushed reservoir almost has no residual oil potential; the potential of weak and medium flushed reservoir is higher.

D. There is a certain potential in flushed layer of region A. The potential of improving displacement efficiency is 57.07%, among which the potential of class III is 18.43%, the potential of class II is 24.72%, and the potential of class I is 13.92%. At the same time, there is a potential to expand the affected volume 27.92 % in region A (class I 24.54%, class II 2.49 %, class III 0.89%).

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Table 6  Remaining oil distribution of various layers in region A

| Washing degree | Thickes ratio (%) | Remaining oil in washing layers | Proportion in total remaining oil |
|----------------|------------------|---------------------------------|----------------------------------|
|                |                  | Residual oil saturation      | Low       | Medium | High        | Residual oil saturation | Low | Medium | High |
|                |                  | 30%<So<40% | 40%<So<50% | 50%<So<60% | So<30% | 30%<So<40% | 40%<So<50% | 50%<So<60% | So<30% |
| strong | 20.75 | 65.42 | 8.83 | 0 | 13.57 | 6.81 | 0.36 |   |
| medium | 40.45 | 2.94 | 27.97 | 56.32 | 12.76 | 1.19 | 11.32 | 22.78 | 5.16 |
| weak | 10.65 | 0 | 2.91 | 14.88 | 82.21 | 0 | 0.31 | 1.58 | 8.75 |
| none | 28.15 | 0.83 | 3.17 | 8.83 | 87.17 | 0.23 | 0.89 | 2.49 | 24.54 |

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