Analysis of Oil Displacement Efficiency of Subsequent Water Flooding Reservoir by Polymer Flooding

Jing Sun *
The No. 2 Branch of the third Oil Production Corporation of Daqing Oilfield, China

*Corresponding author e-mail: sun_jing@petrochina.com.cn

Abstract. After many years of development of basic well pattern and polymer flooding, the block reservoir has high comprehensive water cut, high water flooded degree and high proportion of water absorbing thickness of high permeability reservoir. In this paper, the water flooding characteristics of each sedimentary unit in the subsequent water flooding reservoir of polymer flooding, the existence and quality of oil in pores, the oil displacement efficiency and the factors affecting the oil displacement efficiency are analyzed based on the data of water flooded layer of updated wells and the coring data of new wells in recent years.

Keywords: Comprehensive water cut, flooding, coring, oil displacement efficiency.

1. Mining status

1.1. The comprehensive water cut of oil wells is high, and the proportion of high water cut wells is high

The comprehensive water cut of subsequent water flooding is high. In August, 1996, the west block of polymer subsequent water flooding was put into polymer injection development, and the five-point method with 250m well spacing was used to arrange the wells. In May, 2003, polymer injection was completely stopped and then transferred to subsequent water flooding development. Up to now, the subsequent water flooding has been going on for 17 years. Before drilling and closing in December, 2019, the average daily liquid production of 53 normal production wells was 113.2t, and the average daily oil production of 53 wells was 2.3tt. The comprehensive water cut was 97.9%, the produced fluid concentration was 247.9mg/L, and the proportion of wells with water cut higher than 97% was 92.5%.

The comprehensive water cut of the new well is high. In the first half of 2020, 97 new oil wells were drilled in the block. At the end of July, 93 wells had been put into operation with an average single well daily fluid production of 71.8t, an average single well daily oil production of 1.3t, and a comprehensive water cut of 98.1%. The percentage of oil wells with water cut above 97% is 86.0%.

1.2. The proportion of water absorption thickness of high permeability reservoir in injection well is high, and the contradiction between layers is intensified

According to the statistics of isotope water injection profiles of 20 consecutive wells in recent two years, the proportion of effective thickness of water absorption in 2019 will be reduced from 69.5% to 60%. Among them, the oil layer with permeability greater than $800 \times 10^{-3} \mu m^2$ sucked in thickness ratio of...
81.3%, a decrease of 0.3% compared with 2018. The inhalation thickness of the low permeability layer with permeability less than $300 \times 10^{-3} \mu m^2$ was 43.9%, a decrease of 6.3%. The effective thickness of oil layer with permeability between $300 \times 10^{-3} \mu m^2$ and $500 \times 10^{-3} \mu m^2$ is 51.6%, which is a decrease of 14.4%. The effective water absorption thickness of oil layers with permeability greater than 1.0 $\mu m^2$ increases by 9.9m, the absolute water absorption increases by 135.9m3, and the relative water absorption increases by 6.4%. It shows that after polymer flooding, the heterogeneity of oil layer is more serious due to long-term scouring. The higher the permeability, the larger the suction ratio, the greater the interlayer contradiction and the worse the ineffective water injection.

2. Characteristics of flooding

2.1. The vertical waterflooding difference of oil layer is large

According to the statistics of water-flooded layers of 17 renewal wells in this block after 2014, there is a big difference in vertical flooding of oil layers. The highest flooding ratio of BI2 is 65.6%, the lowest flooding ratio of BI1 is 14.6%, and the higher flooding ratios of BI1 and BI3 are 64.6% and 45.8%. The ratio of low flooded thickness is 10.71%, which is mainly distributed in BI1 and BI4 sedimentary units.

2.2. The proportion of strong water washing and extremely strong water washing is large

According to the sidewall coring data of four newly drilled wells in 2020, 68 cores and 27 sublayers were taken in oil layers. According to comprehensive interpretation, there are 1 low water flooded layer, 2 medium water flooded layers, 5 medium high water flooded layers, 11 high water flooded layers and 8 extremely high water flooded layers. The ratio of layers and thickness of high and extra-high water flooding is 70.34% and 72.4%. Gas chromatographic analysis showed that the number of strong and extremely strong water washings was 63, accounting for 92.6% of the coring number. For example, 23 cores were taken from the reservoir of well 021. According to the comprehensive interpretation, one was washed by weak water, one by medium water, 12 by strong water and 9 by extremely strong water. Gas chromatography analysis showed that the proportion of strong water washing thickness was 38.3%, saturated hydrocarbon gas chromatography analysis showed that the response value was low. Fluorescense microscopic image showed that the content of luminescent asphalt was mainly water-soluble hydrocarbon, and the luminous area of water-soluble hydrocarbon reached 77.26%. The ratio of very strong washing thickness is 48.6%. The analysis of saturated hydrocarbon gas chromatography shows that the response value is very low.

![Figure 1. Gas chromatographic analysis spectrum of No.19 formation in well 021](image-url)
2.3. The content of water-soluble hydrocarbon in pores is high
From the fluorescence microscopic images of 68 sidewall coring particles, the luminescent asphalt mainly exists in throat shape and intergranular adsorption shape, with moderate luminous intensity and weak color difference. The content of luminous asphalt is mainly water-soluble hydrocarbon, with luminous area ranging from 40% to 75%, followed by oily asphalt and colloidal asphalt, with luminous area ranging from 15% to 40% for oily asphalt and from 10% to 20% for colloidal asphalt.

According to the pyrolysis analysis data of oil reservoir rocks, the average gaseous hydrocarbon content is 0.11mg/g, light hydrocarbon content is 19.15mg/g, accounting for 59.28% of the total hydrocarbon, and heavy hydrocarbon content is 13.04mg/g, accounting for 40.36% of the total hydrocarbon. Total hydrocarbon values of BI1 and BI4 are high, which are 47.43mg/g and 43.85mg/g, respectively, and the lowest value of BI3 is 29.21mg/g. With the increase of water flooded level, the content of light hydrocarbon, heavy hydrocarbon and total hydrocarbon decreased, while the oil quality showed an upward trend.

| Deposit. unit | Total hydrocarbon value (mg/g) | Gaseous hydrocarbon (mg/g) | Light hydrocarbon (mg/g) | Heavy hydrocarbon (mg/g) | Oiline. | Floodin. level | Numb. of coring | Total hydrocarbon value (mg/g) | Gaseous hydrocarbon (mg/g) | Light hydrocarbon (mg/g) | Heavy hydrocarbon (mg/g) | Oiline. |
|--------------|--------------------------------|---------------------------|-------------------------|-------------------------|--------|---------------|----------------|--------------------------------|---------------------------|-------------------------|-------------------------|--------|
| BI1          | 47.43                          | 0.03                      | 23.82                   | 23.59                   | 1.01   | low           | 1              | 83.53                           | 0.00                      | 35.46                   | 48.07                   | 0.74    |
| BI2          | 35.26                          | 0.32                      | 20.27                   | 14.66                   | 1.38   | medium        | 3              | 49.74                           | 0.08                      | 25.75                   | 23.97                   | 1.07    |
| BI3          | 29.21                          | 0.06                      | 17.93                   | 11.21                   | 1.60   | medium        | 15             | 42.07                           | 0.37                      | 24.59                   | 17.08                   | 1.44    |
| BI4          | 43.85                          | 0.07                      | 27.24                   | 16.54                   | 1.65   | high          | 30             | 30.39                           | 0.06                      | 18.51                   | 11.82                   | 1.56    |
| Total        | 32.31                          | 0.11                      | 19.15                   | 13.04                   | 1.47   | extreme high  | 19             | 22.21                           | 0.03                      | 13.99                   | 8.20                    | 1.71    |

3. Oil displacement efficiency
3.1. BI1-4 reservoir has high oil displacement efficiency
According to the sidewall coring data of new wells, 68 cores were cored in BI1-4 oil layer, with an average effective porosity of 29.24% and an average original oil saturation of 77.97%. At present, the oil saturation is 47.21%, and the average oil displacement efficiency is 39.46%, which is higher than other oil layers.
Table 3. Oil displacement efficiency statistics of sidewall coring wells

| Oil formation | Number of coring (pieces) | Effective porosity (%) | Oil displacement efficiency (%) |
|---------------|---------------------------|------------------------|---------------------------------|
| A0            | 3                         | 24.00                  | 0.00                            |
| AII           | 100                       | 29.65                  | 34.66                           |
| AIII          | 83                        | 29.72                  | 40.28                           |
| BI1-4         | 68                        | 29.24                  | 39.46                           |
| BI5-7         | 15                        | 28.11                  | 35.61                           |
| BI2           | 37                        | 29.79                  | 31.91                           |
| CI            | 28                        | 28.68                  | 25.88                           |

3.2. High oil displacement efficiency of well-developed reservoirs
There are differences in the vertical development of oil layers, and BI2 and BI3 oil layers are well developed. BI2 sedimentary unit belongs to meandering river sedimentary type in flood plain, which is dominated by river channel sedimentary development. BI3 sedimentary unit belongs to braided river sedimentary type in flood plain, with obvious braided river sedimentary characteristics, large sand body thickness and good sand body continuity. The permeability and permeability ratio of the two sedimentary units are 0.591 ~ 0.638 μm² and 3.148 and 3.527, respectively. The heterogeneity in BI1 and BI4 units is strong, and BI1 sedimentary unit belongs to the sand body sedimentary type of meandering distributary channel on distributary plain facies water, with permeability of 0.412μm² and permeability ratio of 5.816. BI4 sedimentary unit belongs to internal front facies underwater distributary channel sand body deposition, which is developed in underwater distributary channel sand body and poor in oil layer development. However, due to the undercut of BI3 oil layer, the permeability is 0.424μm² and the permeability ratio is 8.396, which is slightly higher than that of BI1 unit. According to the coring data of new wells, the oil displacement efficiency of BI2 and BI3 reservoirs with better sedimentation is higher, which are 40.78% and 40.45% respectively. At present, the oil saturation is 48.42% and 45.78%, the highest oil displacement efficiency of subzone is 54.8% and 50.2%, and the oil saturation is 34.9% and 41.4%. The displacement efficiency of BI4 is 34.7%, the remaining oil saturation is 52.35%, and the minimum displacement efficiency of BI1 is 28.28%, and the remaining oil saturation is 54.66%.

3.3. Influencing factors of oil displacement efficiency
Reservoir sedimentation, development and well pattern perfection directly affect reservoir flooding and oil displacement efficiency.
Rhythm of oil layer leads to the difference of oil displacement efficiency. From the rhythm of oil layers, the oil layers with effective thickness ≥5.0m are mainly multi-stage and multi-rhythm, and the effective thickness ratio is 87.0%. For oil layers with effective thickness of 2.0~5.0m, the ratio of positive rhythm to multi-stage and multi-rhythm effective thickness is equal, but in the process of water flooding, influenced by gravity, a dominant seepage channel is formed at the bottom of the oil layer, the top of the oil layer is difficult to spread, and the bottom of the thick oil layer with positive rhythm is flooded with high degree. The injection water of multi-stage and multi rhythm oil layers is pushed along the high permeability reservoir, which leads to different oil displacement efficiency. For example, the effective thickness of Bi3 in B20 well is 5.6m, and the multi-stage and multi rhythm are multi-stage. The core data of the well wall shows that the degree of water flooding and oil displacement efficiency of each small layer have obvious multi-stage and multi rhythm characteristics.

Imperfect well pattern leads to the difference of oil displacement efficiency. Due to the influence of fault shielding and the phase change at the edge of river channel, the connectivity of oil layers in local areas becomes poor or disconnected, which leads to the imperfect injection-production relationship between oil and water wells and the difference of flooding levels. For example, in Gengb32 well, in the fault zone, the BI3 sublayer is moderately flooded, and the current oil saturation is 51.5%, and the oil displacement efficiency is 33.84%, which is 6.61 percentage points lower than the average value of coring wells by 40.45%.

Poor reservoir development leads to the difference of oil displacement efficiency. Due to the development of thin sand and sheet sand bodies with relatively poor physical properties among river channel sand bodies, the connectivity of sand bodies on the plane is poor, and the permeability values are quite different, resulting in poor or ineffective local oil layers, resulting in different flooding degrees and different oil displacement efficiencies. The oil displacement efficiency of BI1 is lower than that of BI2 and BI3 sedimentary units.

4. Some realizations
4.1 There are great differences in vertical flooding of oil layers, and the proportion of strong water washing and extremely strong water washing is large.
4.2 Luminous asphalt mainly exists as throat and intergranular adsorption. The content of luminescent asphalt is mainly water-soluble hydrocarbon. With the increase of flooding grade, the content of light hydrocarbon, heavy hydrocarbon and total hydrocarbon decreases, and the oil quality shows an upward trend.
4.3 The oil displacement efficiency of oil layer is higher than that of other oil layers, and the oil displacement efficiency of BI2 and BI3 is higher vertically.
4.4 The difference of waterflooding is affected by the rhythm of oil layer, the perfection of well pattern injection and production and the development of oil layer.

References
[1] Sui Xinguang, "Study on Internal Building Structure of Meandering Channel Sandbody", Daqing Petroleum Institute, Ph.D.
[2] Zhu Xiaomin, "Sedimentary Petrology", Petroleum Industry Press, September 2008.
[3] Wang Long, "Study on the internal building structure of the channel sand body in the horizontal well block of Xingliu District", Daqing Petroleum Institute, March 2009.
[4] Ma Shizhong, Yang Qingyan, "Deposition Model, Three-dimensional Configuration and Heterogeneous Model of Meandering Point Dam", Journal of Sedimentation, 2000, 18(2): 241~247.
[5] Ma Shizhong, "Research on high-resolution sequence stratigraphy, reservoir architecture and heterogeneous model of the river-delta system in the Songliao Basin", Chinese Academy of Sciences: Institute of Geology and Geophysics, 2003.