Research on Oil Layer Protection and Seepage Improvement Capacity Technology in Untabulated Reservoir of Oilfield A

Jinyan Song
No.4 Oil Production Plant, Daqing Oilfield Limited Liability Company, Daqing 163511, Heilongjiang, China
djinyan@petrochina.com.cn

Abstract. On the basis of the experience and practices accumulated in the development of low-permeability untabulated reservoirs in oilfield A, in this paper, oil layer protection and seepage improvement technology of low-permeability untabulated reservoir formed in the well completion process, water injection process and subsequent adjustment process were described, the formation of the above mature technologies has laid the technical foundation for the industrialized development of untabulated reservoir in the oilfield A, and it is of great significance to the effective and efficient development of this type of oil layer.

Keywords: untabulated reservoirs, oil layer protection technology, seepage improvement capacity technology.

1. Introduction
After more than 50 years of efficient development, oilfield A has now entered into the ultra-high water cut development stage, the difficulty of stabilizing crude oil output is gradually increasing, however, the three-low and difficult-to-exploit off-surface reservoir with low permeability (about 10md), low use degree (about 15%), and low produced degree (less than 10%) has become the potential replacement reservoir with sustained and stable output, which is highly valued by oilfield development workers. The geological reserves of untabulated reservoir in oilfield A are 7.4×108t [1], however, affected by the nature of its own reservoir, this type of reservoir has low seepage capacity, and is susceptible to pollution, which causes seepage capacity further drop, for this reason, it is necessary to explore oil layer protection and seepage improvement capacity technology of low-permeability untabulated reservoir, and it is of great significance to the effective development of this type of reservoir.

2. Geological Features

2.1. Reservoir development feature
AFFECTED BY THE COMPLEX SEDIMENTARY ENVIRONMENT OF THE RIVER-DELTA SYSTEM, DIFFERENT TYPES OF UNTABULATED RESERVOIRS HAVE BEEN FORMED, HOWEVER, UNDER THE OVERALL ENVIRONMENTAL CONDITIONS, THE SINGLE LAYER WITH THIN THICKNESS, MANY INTERLAYERS, FINE PARTICLE, HIGH MUDDY CONTENT, POOR SORTING PERFORMANCE, DENSE CEMENTATION, MANY MICROPORES, AND LOW POROSITY, PERMEABILITY AND OIL SATURATION ARE COMMON FEATURES. LOW-PERMEABILITY UNTABULATED RESERVOIR IS THE NATURAL CONTINUATION OF RESERVOIRS
in space, it is mainly developed in the top, bottom, surrounding and internal variation zones of reservoir, it can be divided into breach flooding type, local variation type, aggregation type and stable sand mat type four deposition modes. Production condition are mainly oil spots and oil immersion, the ratio of quartz to feldspar accounts for more than 75%, and the muddy content is relatively high, the ratio accounts for 55.1%.

2.2. Fluid seepage feature
There is non-Darcy seepage feature in the untabulated reservoir of oilfield A[2]. The test results of laboratory research and mine show (as shown in Fig.1) that the starting pressure gradient of this type of reservoir increases with the decrease of oil layer permeability. When the permeability is less than $4 \times 10^{-3} \mu m^2$, the starting pressure gradient increases sharply with the decrease of permeability, when the permeability is greater than $4 \times 10^{-3} \mu m^2$, the non-Darcy seepage feature is significantly weakened. Furthermore, the research on the relative permeability curve shows (as shown in Fig.2) that the relative permeability curve of the water phase is mainly linear type with small slope, accounting for 75.0%, with the increase of water saturation, the relative permeability of the oil phase decreases rapidly, the end of the curve is low, the relative permeability of the water phase is low, the water saturation at the intersection of the relative permeability curves of the oil and water phases is high, the span of the two-phase seepage area is small, the oil displacement efficiency is low, and the development is more difficult.

![Fig. 1](image1.png) the relationship curve between starting pressure gradient and permeability

![Fig. 2](image2.png) relative permeability curve

3. Influencing Factors of Reservoir Seepage Capacity
The throat radius is the main factor that determines the reservoir seepage capacity. The experimental data of constant-speed pressurized mercury of 10 untabulated reservoir cores with different permeability show the pore radius distribution of untabulated reservoir cores with different permeability is not much different (as shown in Fig.3), however, the throat radius is quite different (as shown in Fig.4), and the permeability decreases sharply as the throat radius decreases.
4. Reservoir Protections and Seepage Improvement Technologies

The main object of protection and improvement seepage capacity of untabulated reservoir is the throat structure inside the reservoir, the first is to reduce oil layer pollution and protect the throat radius, we can adopt methods such as optimizing construction technology, improving the quality of injected water and changing fluid properties to achieve the purpose of oil layer protection; the second is the measure improvement, promote the generation of micro-cracks in the area near the well, increase the throat radius, and improve the seepage capacity.

4.1. Well completion technology

4.1.1. Negative pressure perforation technology. Negative pressure perforation is to lower the liquid level in the wellbore before perforation (about 500m); this causes the static pressure in the wellbore to be lower than the formation pressure, after the perforation, the negative pressure impact backflow is used to flush the compaction zone and the perforation channel, which improves the diversion of the perforation pore. This technology has been applied in 273 oil-water wells, it is compared with conventional perforation well completion ways (as shown in Table 1~2), the injection intensity has been increased from 3.6m³/dm to 4.5m³/dm, it increases by 0.9m³/dm, the fluid production strength increases from 0.63t/dm to 0.96t/dm, it increases by 0.33t/dm.
Table 1. Statistics of injection results of water injection wells with different well completion ways

| well completion technology | number of wells | injection condition | pressure (MPa) | allocated injection (m³) | real injection (m³) | injection intensity (m³/d.m) |
|---------------------------|-----------------|---------------------|----------------|-------------------------|---------------------|-----------------------------|
| negative pressure         | 93              | 11.46               | 66             | 64.8                    | 4.50                |
| conventional              | 67              | 12.07               | 50             | 43.4                    | 3.60                |

Table 2. Statistics of production effect of oil wells with different well completion ways

| well completion technology | number of wells | production condition | daily fluid output (t) | daily oil output (t) | moisture content (%) | fluid producing intensity (t/d.m) | oil production intensity (t/d.m) |
|---------------------------|-----------------|----------------------|------------------------|---------------------|----------------------|----------------------------------|---------------------------------|
| negative pressure         | 180             | 12.9                 | 3.8                    | 70.50               | 0.96                 | 0.28                             |
| conventional              | 97              | 8.6                  | 1.5                    | 83.14               | 0.63                 | 0.11                             |

4.1.2. Subdivided flow limit fracturing technology. The subdivided flow limit fracturing well completion technology is based on the old flow limiting fracturing completion technology, the number of designed fracturing layers has been increased from 4 to 7, it reduces the influence of interlayer heterogeneity of oil layers, effectively increases the number of small layers of pressed low-permeability reservoir, and improves the seepage capacity of low-permeability reservoir. This technology has been applied in 327 oil-water wells, compared to conventional flow limiting well completion ways (as shown in Table 3~4), the injection intensity has been increased from 4.1 m³/dm to 5.2 m³/dm, which increases by 1.1 m³/dm, and fluid producing intensity increases from 0.97 t/dm to 1.39 t/dm, which increases by 0.42 t/dm.

Table 3. Statistics of injection results of water injection wells with different well completion ways

| well completion technology | number of wells | number of designed fracturing layers | pressure (MPa) | allocated injection (m³) | real injection (m³) | injection intensity (m³/d.m) |
|---------------------------|-----------------|-------------------------------------|----------------|-------------------------|---------------------|-----------------------------|
| subdivided flow limit     | 154             | 6.2                                 | 9.91           | 41                      | 44.0                | 5.20                        |
| conventional flow limit    | 72              | 3.7                                 | 10.07          | 45                      | 41.4                | 4.10                        |

Table 4. Statistics of production effect of oil wells with different well completion ways

| well completion technology | number of wells | number of designed fracturing layers | daily fluid output (t) | daily oil output (t) | moisture content (%) | fluid producing intensity (t/d.m) | oil production intensity (t/d.m) |
|---------------------------|-----------------|-------------------------------------|------------------------|---------------------|----------------------|----------------------------------|---------------------------------|
| subdivided flow limit     | 173             | 6.6                                 | 14.6                   | 3.9                 | 73.29                | 1.39                            | 0.37                            |
| conventional flow limit    | 51              | 3.8                                 | 11.1                   | 2.4                 | 78.38                | 0.97                            | 0.21                            |

4.2. Upgrade and optimization technology of water injection quality
The oilfield A is a heterogeneous reservoir with high, medium and low permeability at the same time, in allusion to the special situation of low permeability untabulated reservoirs that are susceptible to water injection quality pollution, different mining objects adopt different water injection quality index standards and requirements, water injection of low-permeability untabulated reservoirs requires upgrading the injection water quality, meet the "552" water quality standard requirements (as shown in Table 5), reduce oil layer pollution and protect oil layer permeability.
Table 5. Water injection quality index standards of reservoirs with different permeability

| reservoir classification          | water quality index standard | Oil (mg/L) | suspended matter (mg/L) | median size of particle (μm) |
|----------------------------------|-----------------------------|------------|-------------------------|-----------------------------|
| medium-high permeability         | 20 20 0.5                  | 20         | 20                      | 5                           |
| low permeability                 | 5 5 2                       | 5          | 5                       | 2                           |

4.3. Supporting adjustment technology

4.3.1. Bio-enzyme unblocking technology. Bio-enzymes can peel off the oil film on the rock surface, change the wettability, reduce the interfacial tension, and improve the seepage ability, moreover, it can be reusable, biodegradable, and has environmental protection properties. According to the laboratory experimental data (as shown in Table 6), the permeability can be restored to about 100% after bio-enzyme is unblocked, 20 oil production wells are applied in the field, the average daily oil increase of a single well is 2.3t, the validity period reaches 253 days, and the cumulative oil increase reaches 482t, and it is suitable for near-well unblocking of oil production wells.

Table 6. Experimental data of seepage improvement capacity environmental protection enzyme

| model number | enzyme type | slug volume (PV) | solvent | Concentration (%) | Permeability (μm²) normal | Permeability (μm²) after pollution | Permeability (μm²) after unblocking | recovery rate K3/K1 (%) |
|--------------|-------------|------------------|---------|-------------------|---------------------------|------------------------------------|-------------------------------|-----------------------|
| 9#           | A           | 1.0              | formation water | 8          | 0.197            | 0.163                              | 0.192                          | 97.38                 |
| 7#           | A           | 0.3              | formation water | 8          | 0.362            | 0.317                              | 0.369                          | 101.89                |
| 6#           | A           | 1.0              | formation water | 4          | 0.287            | 0.244                              | 0.315                          | 109.57                |
| 11#          | S           | 1.0              | formation water | 8          | 0.324            | 0.267                              | 0.349                          | 107.72                |

4.3.2. Surfactant unblocking technology. Surfactant has the functions of dissolving heavy hydrocarbons, reducing interfacial tension and improving seepage capacity. According to laboratory experimental data (as shown in Table 6), after unblocking, the decline of injection pressure is about 50%, it is applied in 208 water injection wells, the average single well pressure decreases by 1.0 MPa, the daily injection increases by 15 m³, and the effective period is 396 days, the cumulative injection increases by 3,826 m³; it increases the injection by 2000 m³ more than conventional acidification, and it is suitable for near-well unblocking and injection enhancement of water injection wells.

Table 7. Experimental data of seepage improvement capacity with surfactant

| model number | Permeability (md) | water flood injection pressure (MPa) | surfactant Concentration (%) | pressure after unblocking(MPa) | Pressure decline (%) |
|--------------|-------------------|--------------------------------------|----------------------------|--------------------------------|---------------------|
| 7-3          | 80.5              | 0.40                                 | 0.5                        | 0.19                           | 50.2                |
| 7-4          | 78.7              | 0.39                                 | 0.5                        | 0.15                           | 62.3                |
| E1           | 28.0              | 2.50                                 | 0.5                        | 1.30                           | 48.0                |
| E2           | 28.0              | 2.00                                 | 0.5                        | 0.78                           | 61.0                |
| C7           | 25.0              | 2.20                                 | 0.5                        | 0.80                           | 63.6                |
| C8           | 25.0              | 2.60                                 | 0.5                        | 1.00                           | 61.5                |
| 7-5          | 3.4               | 1.20                                 | 0.5                        | 0.73                           | 39.2                |
| 7-7          | 4.3               | 2.70                                 | 0.5                        | 1.55                           | 42.6                |
| 7-8          | 5.3               | 2.10                                 | 0.5                        | 1.20                           | 42.8                |
| 7-6          | 3.0               | 2.70                                 | 0.5                        | 1.60                           | 40.7                |
5. Conclusion

(1) The seepage capacity of low-permeability reservoir is mainly affected by the throat radius, its seepage capacity; oil layer protection and seepage capacity improvement mainly require various protective measures with the throat radius.

(2) The protection and effective development of low-permeability reservoirs run through the whole process of oilfield development, corresponding protection measures need to be taken in every link of drilling, well completion, water injection and dynamic adjustment.

(3) The protection of low-permeability reservoir can achieve the purpose of protecting oil reservoirs and improving seepage capacity via the improvement of well completion technology, the upgrade of water injection quality, and the change of unblocking fluid properties.

References

[1] Ji Bingyu, Li Yanxing. Main Technical Countermeasures of Enhanced Oil Recovery during High Water Cut Stage in La-Sa-Xing Reservoirs [J]. Petroleum Geology & Oilfield Development In Daqing, 2004, 23 (5): 94~95.

[2] Zhang Jun, Li Xiusheng, Ma Xinfang, et al. Non-Darcy Flow Microscope Description and Impact on Low Permeability Reservoir Development [J]. Special Oil & Gas Reservoirs, 2008, 15(3): 52~55.

[3] Wei Jide. Distribution Characteristics and Controlled Factors of Residual Oils in Daqing Oilfield [J]. Oil & Gas Geology, 2001, 22(1): 57-59.