Research on the adjustment boundary of well pattern injection-production structure in the eastern area of South Second District

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Abstract: Since the "Eighth Five-Year Plan", the practice of extracting fluid from low-water-cut wells and controlling fluid from high-water-cut wells has controlled the increase in water cut and the growth rate of fluid production, and achieved the goal of stabilizing oil and water. At present, the water cut of each well pattern is basically close, and the potential for structural adjustment is small. The effect of continuing to adhere to the previous adjustment of injection-production structure is not obvious. It is necessary to revise the injection-production structure adjustment policy to achieve balanced production of various oil layers and control production decline.

1. Introduction
Since the "Eighth Five-Year Plan", the practice of extracting fluid from low-water-cut wells and controlling fluid from high-water-cut wells has controlled the increase in water cut and the growth rate of fluid production, and achieved the goal of stabilizing oil and water. At present, the water cut of each well pattern is basically close, and the potential for structural adjustment is small. The effect of continuing to adhere to the previous adjustment of injection-production structure is not obvious. It is necessary to revise the injection-production structure adjustment policy to achieve balanced production of various oil layers and control production decline.

Entering the development stage of the ultra-high water cut period, the water cuts of each well pattern are close, the room for structural adjustment is small, the remaining oil distribution is more scattered, and it is more and more difficult to tap the potential of measures and control the decline. Entering the development stage of the ultra-high water cut period, the water cuts of each well pattern are close, the room for structural adjustment is small, the remaining oil distribution is more scattered, and it is more and more difficult to tap the potential of measures and control the decline.

2. There are currently problems in the eastern area of the South Second District
First, the injection-production rate of thin and poor oil layers is high and the burden is too heavy, so the injection-production structure needs to be optimized reasonably. Since the “Twelfth Five-Year Plan”, through the adjustment of the injection-production structure[1], the proportion of basic primary well pattern water injection has dropped from 42.0% to 38.3%, and the proportion of secondary intensified well pattern water injection has increased from 58.0% to 61.7%. At present, the liquid production ratio of the secondary infill well pattern has reached 51.2%, and the injection and production intensity is high. The water injection intensity of the secondary infill well pattern is 6.21m³/d.m, which is 1.28m³/d.m higher than the basic + primary well, and the fluid production...
intensity is 4.23\text{m}^3/\text{d.m}, 1.39\text{m}^3/\text{d.m} higher than basic + primary well; secondary infill well pattern water injection well oil allowable pressure difference is only 1.16 MPa, the proportion of wells with allowable oil pressure difference <1 MPa reaches 44.67%, basic + primary well height ratio 12.46%, the overall performance is the heavy burden of thin and poor oil layers.

Table 1 Statistics of injection and production conditions in the eastern part of South Second District

| Well pattern | Annual water injection (104m^3) | Open well converted strength (m^3/d.m) | Full well converted strength(m^3/d.m) | Annual fluid production (104t) | Converted strength (m^3/d.m) |
|--------------|---------------------------------|----------------------------------------|--------------------------------------|--------------------------------|----------------------------|
| basis        | 41.08                           | 6.45                                   | 4.07                                 | 70.81                          | 3.14                       |
| once         | 130.01                          | 6.90                                   | 5.20                                 | 108.79                         | 4.03                       |
| Twice        | 275.47                          | 7.15                                   | 6.21                                 | 188.47                         | 5.01                       |
| Total        | 446.55                          | 7.02                                   | 5.65                                 | 368.07                         | 4.23                       |

Table 2 Statistics of injection pressure of water injection wells in the eastern part of South Second District

| Well pattern | Number of wells (ports) | Oil pressure (MPa) | Oil allowable pressure difference (MPa) | Numb er of wells (ports) | Oil pressure (%) | Oil allowable pressure difference (MPa) | Num ber of wells (ports) | Oil pressure (%) | Oil allowable pressure difference (MPa) |
|--------------|-------------------------|-------------------|----------------------------------------|--------------------------|-----------------|----------------------------------------|--------------------------|-----------------|----------------------------------------|
| basis        | 7                       | 10.9              | -1.6                                   | 1                        | 9.09            | 12.9                                   | -0.4                     |                 | -0.7                                   |
| once         | 34                      | 10.4              | -1.42                                  | 8                        | 16.67           | 11.84                                  | -0.24                    | 10              | 20.83                                 |
| Basic + one  | 41                      | 10.49             | -1.45                                  | 9                        | 15.25           | 11.64                                  | -0.34                    | 10              | 16.95                                 |
| subtotal     |                         |                   |                                        |                          |                 |                                        |                          |                 |                                        |
| Twice        | 91                      | 10.41             | -1.16                                  | 25                       | 24.27           | 11.31                                  | -0.33                    | 21              | 20.39                                 |
| Total        | 132                     | 10.32             | -1.4                                   | 34                       | 20.99           | 11.43                                  | -0.33                    | 28              | 17.28                                 |

The second is the low submergence of mechanical mining wells and the uneven formation pressure. There are 226 mechanical production wells in the South Second East area, with an average sinking degree of 190m per well. Among them, the average sinking degree of pumped wells is 179m, which is 18m lower than that of the whole plant. The proportion of high-pressure well points is 36.84%, and the proportion of low-pressure well points is 28.95%.[2]
Table 3 Statistics of submergence classification of oil production wells in the eastern part of South Second District

| Well pattern | ≤100m | 100m-200m | 200m-300m | >300m | Total |
|--------------|-------|-----------|-----------|-------|-------|
| Number of wells (ports) | Submergence (m) | Number of wells (ports) | Submergence (m) | Number of wells (ports) | Submergence (m) | Number of wells (ports) | Submergence (m) |
| Pumping unit | 18 | 81 | 137 | 142 | 39 | 237 | 13 | 541 | 207 | 179 |
| Electric pump | 1 | 151 | 3 | 219 | 2 | 403 | 6 | 269 |
| Screw pump | 1 | 126 | 6 | 244 | 6 | 427 | 13 | 319 |
| Total | 18 | 81 | 139 | 142 | 48 | 236 | 21 | 496 | 226 | 190 |

Table 4 Statistical table of submergence classification of oil production wells in the eastern part of South Second District (pumping wells)

| Well pattern | ≤100m | 100m-200m | 200m-300m | >300m | Total |
|--------------|-------|-----------|-----------|-------|-------|
| Number of wells (ports) | Submergence (m) | Number of wells (ports) | Submergence (m) | Number of wells (ports) | Submergence (m) | Number of wells (ports) | Submergence (m) |
| Basis | 5 | 142 | 5 | 221 | 3 | 506 | 13 | 257 |
| Once | 8 | 79 | 42 | 139 | 9 | 244 | 3 | 622 | 62 | 171 |
| Twice | 10 | 83 | 90 | 143 | 25 | 237 | 7 | 505 | 132 | 176 |
| Total | 18 | 81 | 137 | 142 | 39 | 236 | 13 | 541 | 207 | 179 |

Table 5 Statistics of formation pressure classification in the eastern part of South Second District

| Item | ≥1.0MPa | 0.5 ~ 1.0MPa | -0.5 ~ 0.5MPa | -0.5 ~ -2.5MPa | ≤-2.5MPa | Total |
|------|---------|--------------|---------------|----------------|----------|-------|
| Number of wells (ports) | 9 | 5 | 13 | 7 | 4 | 38 |
| Proportion (%) | 23.68 | 13.16 | 34.21 | 18.42 | 10.53 | 100 |
| Formation pressure (MPa) | 12.08 | 11.67 | 10.71 | 9.48 | 7.98 | 10.65 |
| Total pressure difference (MPa) | 1.47 | 0.71 | 0.20 | -0.90 | -3.07 | 0.02 |

Third, the water cut difference between well patterns is small, the room for structural adjustment is small, and the proportion of low-yield wells is high. At present, the water cut of each well pattern has reached more than 95%, and the water cut between the basic well pattern and the secondary infilled well pattern is only 1.38%, and the water cut difference between the well patterns is small. Among the 226 production wells in the block, 41 have a daily oil production of less than 1t, accounting for 18.1%.

Table 6 Statistics of the production situation of each well pattern in the eastern part of South Second District

| Well pattern | Total | Among daily oil production <1t |
|--------------|-------|-------------------------------|
| Number of wells (ports) | Daily fluid production (t) | Daily oil production (t) | Comprehensive water cut (%) | Number of wells (ports) | Daily fluid production (t) | Daily oil production (t) | Comprehensive water cut (%) |
| Basis | 25 | 85 | 2.6 | 96.94 | 3 | 60 | 0.7 | 98.74 |
| Once | 65 | 50 | 2.0 | 95.90 | 5 | 24 | 0.6 | 97.33 |
| Twice | 136 | 41 | 1.8 | 95.56 | 33 | 22 | 0.7 | 96.93 |
| Total | 226 | 48 | 2.0 | 95.93 | 41 | 25 | 0.6 | 97.29 |
The fourth is from the analysis of remaining oil potential: mainly concentrated in the Sa III and Pu II oil layers, the remaining geological reserves ratio is 42.52%; from the perspective of the production of various sedimentary types, the remaining potential is mainly concentrated in the medium and high permeability oil layers. The proportion of geological reserves is 73.88%.

Table 7 Comparison table of production situation of each oil layer group in the eastern part of South Second Area

| Oil layer group | Geological reserves | 2018.12 Reserve utilization |
|-----------------|---------------------|-----------------------------|
|                 | Reserves (104t)     | Cumulative oil production (104t) | Recovery degree (%) | Remaining reserves (104t) | The proportion (%) |
| Sa I group      | 271.96              | 114.01                       | 41.92               | 157.95                  | 7.20 |
| Sa II group     | 575.55              | 278.36                       | 48.37               | 297.19                  | 13.54 |
| Sa III group    | 830.19              | 389.94                       | 46.97               | 440.25                  | 20.05 |
| Portuguese I 5+61-7 | 498.75            | 214.71                       | 43.05               | 284.04                  | 12.94 |
| Portuguese group II | 900.01          | 406.80                       | 45.20               | 493.21                  | 22.47 |
| High Group I    | 915.37              | 392.69                       | 42.90               | 522.68                  | 23.81 |
| Total           | 3991.83             | 1796.52                      | 45.00               | 2195.31                 | 100.00 |

Table 8 Comparison of production conditions of various sedimentary types in the eastern part of South Second District

| Deposition type | Geological reserves | 2018.12 Reserve utilization |
|-----------------|---------------------|-----------------------------|
|                 | Reserves (104t)     | Cumulative oil production (104t) | Recovery degree (%) | Remaining reserves (104t) | The proportion (%) |
| Riverway        | 1210.19             | 555.69                       | 45.92               | 654.50                  | 29.81 |
| subject         | 1796.98             | 829.43                       | 46.16               | 967.55                  | 44.07 |
| Non-subject     | 652.61              | 304.45                       | 46.65               | 348.16                  | 15.86 |
| Off-balance sheet | 332.06           | 106.95                       | 32.21               | 225.11                  | 10.25 |
| Total           | 3991.83             | 1796.52                      | 45.00               | 2195.31                 | 100.00 |

Based on the above analysis, although the basic and primary wells have slightly higher water content, the proportion of remaining reserves is large and the water injection intensity is low. Therefore, it is necessary to re-study and re-optimize the current development and adjustment policies, lead the water drive depth adjustment and tap the potential technology to re-innovate, maintain a certain production scale of water drive, and control the rate of decline in production.

3. Basic and primary research on the extraction boundary of dense well pattern

(1) Reasonable extraction limit for theoretical research

Respectively through the reservoir engineering method and the numerical simulation program prediction method, the basic well pattern + one-time infill well pattern of the Nanerdong block is used to extract 50% of the fluid at a rate of 1, 5, 10, and 15 years, and the water cut production change is predicted. The model predicts the final recovery factor of the whole area as shown in the figure: It can be seen from the figure that the two methods predict that the extraction rate has a small effect on the overall recovery factor of the block.[3]
The oil reservoir engineering method is used to predict the 0-100% recovery rate and water cut rising speed of the basic and one-time infill well pattern extraction range. It can be seen that the recovery rate of basic wells and one-time infill wells increases after fluid extraction, and the rate of water cut rises slightly. When the fluid extraction range reaches 55%, the recovery rate increases to the highest value, and the fluid extraction range exceeds 60%. Due to the large fluid extraction range of a single well pattern, the sudden intrusion of some oil layers is gradually obvious, and the water cut rise rate in the whole area is significantly accelerated. The enhanced oil recovery rate decreases, so it can be determined that the upper limit of the basic and one-time infill well pattern extraction range is 60%.

Numerical simulation prediction technology is used to compare the effects of multiple sets of plans. From the prediction results, the basis and the one-time infilling well pattern itself The reasonable extraction range is 55%.
Based on the prediction of the above-mentioned reservoir engineering methods and numerical simulation methods, the reasonable extraction range of basic and one-time infill well patterns is 55-60%.

(2) **Realize the potential of water lifting in combination with on-site capabilities**

First is to control the long shut-in well to restore the water injection potential. At present, 18 basic and primary wells have been shut in. The main reasons for shut-in are 14 wells due to casing change and unmovable shut-in, accounting for 77.8%. The daily injection rate before closing is 1585m³ and the daily actual injection is 1456m³. By confirming the wellsite and casing deformation situation by well, 3 wellsites were seriously under pressure, 1 well could not be repaired due to overhaul, and 14 wells could be restored with water injection. It is expected that the daily water injection rate will be increased by 1,425m³ after all wells are opened.[4]

The second is to increase the pressure of water injection potential. From the perspective of oil allowable pressure differential level, there are 22 wells with basic and primary well pattern oil allowable pressure difference ≥1MPa, and the oil allowable pressure difference is -2.3MPa, accounting for 53.66%, which has a certain water lifting capacity. The water distribution data is used to predict the water volume of each well after the pressure is raised. It is estimated that when the water injection pressure is increased to 0.5MPa, the daily water injection volume can be increased by 943m³.

The third is to enlarge the water nozzle to increase the water injection potential. Judging from the classification of water nozzles in the water injection interval, there are a total of 124 layers of small water nozzles and adjustable water nozzles, accounting for 71.3%. The daily injection is 3200m³, the daily actual injection is 3321m³, and the injection completion rate is 103.78%. Water lifting capacity. After deducting 22 pressure-lifting water injection potential wells, 16 water injection potential wells with enlarged water nozzles have been implemented, with a total of 50 water injection intervals. After all the water nozzles are enlarged to 12mm, it is expected that the daily water injection can be increased by 189m³.

The fourth is to restore the water injection potential of the injection-stop layer. There are a total of 60 injection stop zones in the basic and one-time infilling well patterns. The reason for the injection stop is mainly because of polymer flooding stop injection and casing damage control injection. There are 54 zones in total, accounting for 90% of the total zones. By confirming the stop injection time of the injection stop interval and the dynamics of the surrounding wells before the injection stop, it is possible to resume water injection in 4 intervals and increase the daily water injection by 75m³.

Fifth, the potential of water injection wells to increase injection measures. For the current normal water injection wells with poor water absorption, measures to increase injection have been implemented to improve injection conditions. Combining the causes of poor water absorption and the conditions of the downhole tubing string, 3 wells can be renovated, and it is estimated that 100m³ of water injection can be restored.
Comprehensive analysis of various water-lifting measures, the implementation of the foundation and the maximum water-lifting volume of an infilled well pattern is 2732m³, and the maximum water-lifting rate is 58.7%. If the water cut limit of the water-lifting well layer is initially determined to be below 96%, combined with the results of numerical simulation, the proportion of wells with water content below 96% is 45.2%. Therefore, considering the conditions at both ends of the oil and water wells, the final water lift range is 26.5%, and the calculation basis and one-time infilling well pattern can lift 1235m³ of water.

Table 9 The maximum water extraction range of the foundation and primary infill well pattern water injection wells in the eastern part of the South Second District

| classification | Long shut well governance | Boost water injection | Enlarge the faucet | Stop injection layer recovery | Measures increase | total  |
|----------------|---------------------------|-----------------------|-------------------|-----------------------------|-----------------|-------|
| Water lifting capacity (m³) | 1425 | 943 | 189 | 75 | 100 | 2732 |
| Water lifting range (%) | 30.6 | 20.2 | 4.1 | 1.6 | 2.1 | 58.7 |

4. Prediction of the adjustment effect of basic and primary infilled well pattern extraction

The simulation plan is determined to be basic wells and one-time infill wells to pump 27% of water, which translates into an increase of 10.2% in water injection in the whole area, and implements it in place for 5 years, and extracts liquid evenly every year.

The differential equation of water change deduced by using type A and Sipatchev curve:

Type A:
\[
\frac{df_w}{dt} = Bq_o (1 - f_w) f_w = Bq_i (1 - f_w)^2 f_w
\]

Sipachev:
\[
\frac{df_w}{dt} = \frac{2Bq_i \sqrt{1 - f_w}}{\sqrt{A}} = \frac{2Bq_i (1 - f_w)^{3/2}}{\sqrt{A}}
\]

After the program is tangible, the simulation is carried out. The whole area is expected to increase the recovery rate by 0.22%, the annual control output declines by 1.15%, the annual water cut rises by 0.01%, the average annual water injection increases by 2.0% in the whole district, and the average annual liquid production An increase of 3.1%.
5. Adjustment workload and preliminary results of the test area

Since the adjustment of the area well pattern injection and production structure, the plan has pumped 42 well times, daily allocation injection increased by 505m³, daily actual injection increased by 435m³, water well measures increased by 5 well times, daily actual injection increased by 105m³, and treated 7 long tube wells and opened Daily water injection 300m³ behind the well.

Up to now, the daily water injection volume of the South Erdong area plus one well pattern has increased by 728m³, the liquid production volume has increased by 200t, the oil production has been stable, the water cut has increased by 0.09%, and the injection-production ratio has increased by 0.12%.

6. Conclusion

1. Water flooding has entered the late stage of ultra-high water cut development. At present, the water cuts of each well pattern are basically close, and the potential for structural adjustment is relatively small. The effect of continuing to adhere to the previous injection-production structure adjustment methods is not obvious. The oil-like layer is produced in a balanced way to control the decline in production.

2. Based on reservoir engineering methods and digital model prediction technology, theoretical research has concluded that the reasonable extraction ratio of basic and one-time infill well patterns should be 55-60%, combined with the implementation of on-site water extraction capabilities, and comprehensive consideration of inefficient and ineffective circulation control. The ratio of basic and one-time well pattern extraction is determined to be 27%.

3. Based on the prediction of the block development effect after the foundation and one-time infilled well pattern extraction, although the water cut rises slightly in recent years, the rate of decline in production is well controlled.

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