Test and Application of Shut-in and Step-down Adjustment Technology for Injection Well and Drilling Process

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Abstract. Because the contradiction among layers cause drilling infill well damage the oil layer in the Sazhong area and cause casing to be damaged, it is proposed that injection well shut-in depressurization adjustment technology controls the pore pressure of the layer, achieve the purpose of protecting the casing and the oil layer, moreover, the interlayer pressure difference is reduced, and the well cementation quality of new drilling accordingly is improved. In this paper, the field test of the injection well shut-in depressurization adjustment technology and the application of this technology in the drilling process are studied. The research shows that this technology can be directly applied to the subsequent encryption adjustment wells and the drilling production in the polymer flooding, it is of great significance for reducing the oil layer pollution, protecting the casing and improving the quality of the drilling engineering for subsequent drilling.

Keywords: pore pressure, injection well, shut-in and depressurization, drilling.

1. Introduction

Due to the layered water injection mining in the Sazhong development zone for many years, the layer pore pressure has formed a multi-layer pressure system, and the high pressure layer, the normal pressure layer and the under-pressure layer coexist in the longitudinal section of the single well, contradiction among layers is prominent, when drilling infill adjustment well, in order to ensure the safety of drilling construction, the drilling fluid density is designed and constructed to balance the pressure of the high-pressure oil layer, the pressure of high-permeability main oil layer is low, the drilling mud fluid pressure is greater than pore pressure of main oil layer, and the drilling fluid will infiltrate into the oil layer under the action of positive pressure difference, block the pore throat, reduce the permeability of the layer, and result in oil layer pollution. The problem of patches of casing damage has also occurred in the drilling block, which seriously affects the implementation of development indicators of drilling block. In allusion to the geological characteristics of the Sazhong development area based on the research on distribution law of layer pore pressure, this paper proposes to control the layer pore pressure through the shut-in depressurization adjustment technology of injection well to achieve the purpose of protecting the casing and the oil layer, moreover, the interlayer pressure difference is reduced, the pressure difference will improve the well cementation quality of the new drilling accordingly. This technology
is highly applicable and provides a certain technical guarantee for ensuring that the oil field continues to produce 40 million tons.

2. Research on the Depressurization Law in Water Injection Well

Four wells are selected to carry out drilling bottom test in the east section of the North No.1 District, shut the well through the water injection well, find out the depressurization law of water injection well, determine the shut-in range of the injection well, the drilling distance and the drilling time of different well networks, SFT small layer pore pressure test is carried out on the bottom well, and compare with the layer pore pressure predicted by the well, and determine the relationship between wellhead pressure and layer pore pressure.

2.1. Test content and purpose

(1) The injection wells in each layer of the 300-meter-long continued to carry out injection test during the drilling period, and find out the distribution condition of layer pore pressure under the conditions of 300 m drilling and shut, and determine the reasonable drilling and shut range.

(2) Test the shut-in depressurization trend of injection wells in different layers, find out the depressurization law of water injection wells, and predict the drilling and shut time.

(3) Control the wellhead pressure test of water injection well of main oil layer, and find an operable method to control the wellhead pressure of the main oil layer.

(4) The relationship test between wellhead pressure and layer pore pressure, find the stable main oil layer pressure (the pressure coefficient is stable at 1.00-1.20), the wellhead pressure value of the water injection well among the layers is reduced, it is conducive to reduce oil layer pollution and improve cementing quality of high permeability layer.

2.2. Selection of testing wells

Four wells are selected to carry out drilling bottom test in the first batch of drilling in the first drilling operation area in the east section of the North No.1 District. Based on the principle of taking the complex area as the main and matching the normal injection-production area, three wells are selected in the south of the north 1-3 well and on both sides of the 98th fault, one well is selected in the normal injection-production area in the middle of the block, the well numbers bottom test are: middle 21-P244, middle 12-P242, north 1-41-P242, north 1-61-P251.

2.3. Drilling test methods

(1) Drilling scope: drilling the water injection wells of each layer (including the injection wells with within 30 meters perforation below the well depth), the drilling scope is 300 meters (the original drilling scope is 450 meters), and the undrilled layer (It does not include injection wells within 30 meters perforation below the well depth) does not stop within 300 meters.

(2) Wellhead pressure of water injection well: before the drilling, the wellhead pressure of the main oil layer is 4-5Mpa and wellhead pressure of injection well in differential layer is 3 Mpa.

(3) Drilling time:

- The main oil layer well was closed three days after the injection well of the Sapu oil layer shut, and one well is tested.
- The main oil layer well was closed five days after the injection well of the Sapu oil layer shut, and one well is tested.
- The main oil layer well was closed seven days after the injection well of the Sapu oil layer shut, and one well is tested.

At the same time, four wells drill the first batch of wells, according to the first type of main oil layer water well pressure reduction speed, the shut-in time of the second and third main oil wells is adjusted.
2.4. Control principle of wellhead pressure in the injection well of main oil layer
(1) The injection well of main oil layer 150 meters away from the new drilling well, when the wellhead pressure is less than 1 Mpa, the method of controlling water injection is used to increase the pressure of the main oil layer, the control injection pressure is 5-6 Mpa, when the wellhead pressure is higher than 6 Mpa, the well is shut down (cannot control the injection during well completion, keep the shut-in state).
(2) In order to ensure the safety and quality of drilling, the injection well of main oil layer within 150 meters of the new drilling will not carry out the control pressure test.

2.5. Analysis of test results

2.5.1. Pressure reduction results of water injection well. According to the test plan for water injection well drilling, the main oil layer injection well of Sapu, the injection well of Sapu difference well, and the injection distance of Gaotaizi oil layer injection well are all drilled at 300 meters, but the principle of different drilling time, the wellhead pressure is 4-5Mpa, the wellhead pressure is 3Mpa before the drilling of the Saqian oil layer, and the wellhead pressure is 4Mpa before the Gaotaizi oil layer well drill, there are 27 wells were drilled for four bottom wells, from the depressurization results:

1) Water wells on the water injection well row:
   1 Sapu layer injection well (pressure can be reduced) can be reduced to about 5Mpa in 5-7 days (depressurization inflection point), after that, the pressure is stable and the depressurization is slow.
   2 Sapa layer injection well (pressure reduce fast) can be reduced to 4Mpa in 10-15 days (depressurization inflection point), after that, the pressure is stable and the depressurization is slow.

2) Water wells of non-water injection:
   The Sapa layer injection well can be lowered to 4Mpa (depressurization inflection point) in 7-10 days, after that, the pressure is stable and the depressurization is slow.

3) Gaotaizi injection well:
   Gaotaizi injection well can be reduced to about 5Mpa in 7-9 days (depressurization inflection point), after that, the pressure is stable and the depressurization is slow.

4) Water wells without depressurization:
   Water injection well row, fault blocked area, whether the Sapa good layer or the Sapa poor layer injection well, as long as there is no decompression point, when the pressure drop to a certain level (fail according to the pressure drop standard), it will not fall, we can draw conclusions after analysis, there is no mining point within 400 meters around the injection well (only injection and no production), The injection and production relationship in the region is not perfect.
   The conclusions can be drawn from the test results:
   a. The non-water injection well row of the Sapa good layer and the Sapa poor layer injection well can achieve the requirement according to the drilling test scheme.
   b. The depressurization speed of the Sapa good layer is faster than the injection well of the Sapa poor layer, in addition to the few wells, the well shut down for 7-10 days, which can meet the depressurization requirement before the drilling;
   c. The depressurization speed of few Sapa difference injection wells is slower, the well shut down and cannot meet the depressurization requirements 10-15 days before drilling according to the drilling test scheme.
   d. The Gaotaizi injection well can reach the depressurization requirement according to the depressurization test plan.
   e. There is no mining point within 400 meters around the water injection well row (only injection and no production), the depressurization speed is slow, and it is necessary to take the overflow and pressure reduction measures.

2.5.2. SFT test results of layer pore pressure. 1) Reconnaissance principle:
   Each layer of the oil layer group is selected, and both the high-pressure layer and the low pressure layer are taken into consideration.
2) SFT pressure measurement results
Pressure test results of four well oil layer:
Non-water injection well row: the pore pressure of the oil layer in the 1601-P251 well is: the lowest 0.71 (Sa 1), the highest 1.24 (Sa 3), and the interlayer pressure difference is 3.4Mpa.
Injection well row: the pore pressure of the oil layer in the north 14-1-P242 well is: the lowest 0.78 (Pu I2), the highest 1.64 (Pu 1), and the interlayer pressure difference is 5.9Mpa.
3) Analysis of SFT pressure measurement results
According to the depressurization situation of the drilling well, the pressure measurement results reflect the wellhead pressure of the injection well, and the non-water injection well row: the water injection well is qualified (north 1761-P251), the layer pore pressure coefficient is up to 1.24; injection well row: depressurization of water injection well is unqualified (north 11-4-P242), the layer pore pressure coefficient is up to 1.64. The interlayer pressure difference of the 4 bottom well is between 3.8-5.9Mpa, as shown in the following table:

| well number    | pore pressure coefficient of lowest layer(high-permeability layer) | pore pressure coefficient of highest layer | interlayer pressure difference | pressure reduction condition | comment                  |
|----------------|---------------------------------------------------------------------|--------------------------------------------|-------------------------------|-----------------------------|--------------------------|
| north 1-61-P251| 0.71                                                                | 1.24                                      | 3.4                           | pressure reduction qualify   | normal injection-production area |
| middle12-P242  | 0.89                                                                | 1.35                                      | 3.8                           | pressure reduction qualify   | normal injection-production area |
| middle21-P244  | 1.01                                                                | 1.54                                      | 4.6                           | pressure reduction is unqualified | near fault                |
| North1-41-P242 | 0.78                                                                | 1.64                                      | 5.9                           | pressure reduction is unqualified | north 1-3 well row        |

It can be concluded from the above table that the lower the wellhead pressure water injection well reduces, the smaller the interlayer pressure difference, conversely, the greater the interlayer pressure difference.

Through bottom test of water injection well and comparison with the new drilling SFT pressure data, it is concluded that the pore pressure and interlayer pressure difference of the oil layer are directly proportional to the wellhead pressure of the adjacent pressure-reducing injection well, the higher the wellhead pressure of the pressure-reducing injection well, the greater pore pressure in the new drilling layer, The corresponding interlayer pressure difference is also greater. As long as the wellhead pressure of the injection well can be effectively controlled, the pore pressure of layer can be effectively controlled, the interlayer pressure difference is reduced, the oil layer pollution is reduced, and the drilling construction safety and well cementation quality can be ensured.

3. Practical Application of Shut-in Pressure Reduction in Water Injection Wells during Drilling
Through the depressurization test results of the injection wells of the four bottom wells, the wellhead pressure of the injection well can directly reflect the pore pressure of layer within a certain range, and study the depressurization law of the injection wells in different wells to determine a reasonable drilling
scheme, determine reasonable drilling fluid density, determines the reasonable drilling time and the drilling range; simultaneously studies the maintenance method of high-permeability and low-pressure layer pressure, reduces the interlayer pressure difference by controlling the wellhead pressure of the injection well, reduces the drilling fluid density, so reduce the pollution of the oil layer and protect the casing.

3.1. Determine the depressurization drop law of injection wells in different well network
According to the injection-production relationship of different well networks in Nort No.1 District, representative injection wells were selected for depressurization test, and different well network depressurization trend boards are made, and RFT pressure verification was carried out accordingly.

As can be seen from the above figure: the wellhead pressure of the Sapu main oil layer well can be reduced to less than 4Mpa for 7 days; the wellhead pressure of Pu 1 main oil layer group can can be reduced to less than 2Mpa for 5 days; the wellhead pressure in the normal injection zone Sapu difference oil layer can be reduced to less than 3Mpa for 15 days; The wellhead pressure of the water injection well in the Gaotaizi oil layer can be reduced to below 4Mpa for 13 days, however, the depressurization of injection wells in the injection well row are very slow due to the imperfect injection-production relationship.

3.1.1. Determination of the decompression time of drilling wells in different well networks. 1) The injection wells of the Sa and Pu oil layer and the Gaotaizi oil layer are closed 10-15 days before the drilling.
2) The main oil layers of Sa and Pu are shut down 7-10 days before drilling.
3) The main injection oil layer of the Pu I Group is closed 3-5 days before drilling.

3.1.2. Depressurization distance of water injection well drilling. The depressurization of water injection wells in water injection row is slow, and no decompression point within 400 meters, according to these features, the pressure measurement data is integrated, the injection well of the layer system (including the well that is perforated within 30 meters below the well depth), according to different drilling distances of the well networks:
1) The drilling distance of the injection wells of the Sa and Pu oil reservoirs in the water injection well row is 450m; the water injection well distance of the main oil layer is 300 m.
2) The drilling distance of normal injection-production area of Sapu and Gaotaizi oil layer is 300 meters.
3.1.3. Wellhead Pressure standards for pressure-injection wells before drilling, according to the layer system. 1) High I and II oil layer injection wells are not higher than 4Mpa.  
2) The Sa and Pu difference water injection wells are not higher than 3Mpa.  
3) The injection well of Sa and Pu main oil layer is 4-5Mpa.

3.2. Implement pressure maintaining water injection method to reduce interlayer pressure difference

3.2.1. Determine the relationship between layer pore pressure and interlayer pressure difference. The interlayer pressure difference is related to the pressure coefficient of the high and low pressure layers and the buried depth of the low pressure layer, which reflects the pressure coefficient difference between the high pressure layer and the low pressure layer. There are two ways to reduce the interlayer pressure difference: one is to appropriately increase the layer pressure coefficient of the low-pressure layer, and the other is to reduce the pressure coefficient of the high pressure layer to achieve the purpose of reducing the interlayer pressure difference. Through the drilling test of the east bottom well in the north No.1 district and pressure measurement data, the layer pressure of the adjustment well is related to the depressurization condition of the adjacent injection well, except for individual casing layer, the oil layer pressure and the interlayer pressure difference are directly proportional to the wellhead pressure of the adjacent depressurized well.

Figure 2. The adjacent depressurized well

3.2.2. Pressurized water injection method. Through normal pressure reduction of the injection well and the decompression of the original wellbore, the purpose of reducing the interlayer pressure difference cannot be achieved, how to reduce the interlayer pressure difference, the method of low pressure reinjection is adopted (control water injection) to increase the pore pressure of the main oil layer and reduce the interlayer pressure difference, quantitatively give the wellhead pressure and water injection pressure value of the main oil layer, and this method is called "pressurized water injection".

3.2.3. Pressurized water injection principle. Main oil layer injection well 150 meters away from the new drilling, when the shut-in wellhead pressure is less than 1 MPa, low pressure water injection is used to increase the layer pressure of the main oil layer, interlayer pressure difference is reduced, the control injection of water injection pressure is 5-6 MPa, (the control injection cannot be conducted during the 24 hours from electrical logging to well cementation, keep shut-in status). The injection wells within 150 meters of the new drilling well remain the closed state.
Pressurized water injection test: 20 wells were tested in the section of the north No.1 district, and the test results are as follows:

**Table 2.** Testing condition of pressurized water injection in the section of the north No.1 district

| order number | drilling well number | pressurized water injection number | cumulative water injection volume(m³) | water injection pressure(Mpa) | interlayer pressure difference(Mpa) | cementing quality |
|--------------|----------------------|------------------------------------|--------------------------------------|------------------------------|-----------------------------------|------------------|
| 1            | North 1-61-P245      | North 1-Ding 6-P32                 | 754                                  | 6                            | 3.8                               | high quality     |
| 2            | North 1-62-E62       | North 1-Ding 6-P33                 | 2364                                 | 5.8                          | 3.8                               | high quality     |
| 3            | Middle 11-P244       | North 1-6-45                       | 3134                                 | 5.5                          | 4                                 | high quality     |
| 4            | North 1-41-E62       | North 1-Ding 4-P42                 | 202                                  | 5.5                          | 3.7                               | high quality     |
| 5            | North 1-51-E62       | North 1-Ding 5-P132                | 70                                   | 5.7                          | 3.8                               | high quality     |
| 6            | North 1-6-P255       | North 1-4-P54                      | 1123                                 | 5.6                          | 4.1                               | high quality     |
| 7            | North 1-63-P257      | North 1-6-55                       | 162                                  | 6                            | 3.5                               | high quality     |
| 8            | North 1-63-P253      | North 1-6-new water 36             | 50                                   | 5                            | 3.6                               | high quality     |
| 9            | North 1-4-P259       | North 1-4-P136                     | 1102                                 | 5                            | 3.7                               | high quality     |
| 10           | North 1-6-P248       | North 1-7-P34                      | 943                                  | 5.6                          | 4                                 | high quality     |
| 11           | North 1-61-P42       | North 1-Ding 6-P31                 | 568                                  | 5                            | 3.8                               | qualified        |
| 12           | North 1-44-P255      | North 1-4-P134                     | 267                                  | 5                            | 3.8                               | high quality     |
| 13           | North 1-51-P253      | North 1-41-544                     | 237                                  | 6                            | 4.1                               | high quality     |
| 14           | North 1-62-P251      | North 1-52-544                     | 530                                  | 6                            | 3.5                               | high quality     |
| 15           | North 1-42-P265      | North 1-Ding 4-P54                 | 1220                                 | 6                            | 3.6                               | high quality     |
| 16           | North 1-62-P257      | North 1-51-550                     | 276                                  | 6                            | 3.7                               | high quality     |
| 17           | North 1-62-P257      | North 1-5-p56                      | 15                                   | 6                            | 4                                 | high quality     |
| 18           | North 1-41-P259      | North 1-3-Ding 49                  | 113                                  | 6                            | 3.2                               | high quality     |
| 19           | North 1-3-P258       | North 1-3-Ding 51                  | 32                                   | 5.8                          | 3.8                               | high quality     |
| 20           | North 1-3-P258       | North 1-Ding 4-P48                 | 180                                  | 5.6                          | 3.1                               | high quality     |

The technology can effectively reduce the pore pressure of the high pressure layer, and the low pressure layer does not change under the action of the balanced mud liquid column, therefore, appropriately reducing the proportion of the drilling mud is one of the most effective ways to reduce the interlayer pressure difference and reduce the pollution of drilling to the oil layer.
As can be seen from the interlayer pressure difference data in the above table, the interlayer pressure difference of the 20 wells tested is controlled below 4Mpa, and the wellhead pressure of the Pu I group is controlled at about 1.0 Mpa, the layer pressure of the Pu group I to be drilled is improved by pressurized water injection, the pressure interlayer difference has been reduced, and cementing quality has also been greatly improved, the qualified rate of cementing quality of testing well is 100% and the quality rate is 95%.

3.3. Water injection wells can be recovered to allocated water injection volume step by step

The method of recovering water injection after drilling is also one of the key links to control layer pressure changes. According to the difference of water injection volume, the recovery can be completed step by step, smoothly recover water injection pressure and oil layer pressure. Since 2004, the injection wells have been refilled with water from the previous 1 to 3 steps, and refined to 4 to 5 steps according to allocated water injection volume. The layer pressure is guaranteed to change smoothly. The standard for sub-step water injection is:

(1) Basic well network + Pu I group main oil layer, when the water injection volume is less than 200m³, it is divided into 3 steps, the step length is 10 days, and the recovery is completed in 30 days; when the water injection amount is more than 200m³, it is divided into 4 steps, the step length is 10 days, and return to place in 40 days;

(2) Adjusting the well net + Gaotaizi well net, when the water injection volume is less than 200m³, it is divided into 4 steps, the step length is 10 days, and return to place in 40 days, when the water injection volume is more than 200m³, it is divided into 5 steps, the step length is 10 days, return to place in 50 days.

3.4. Evaluation of application effect

The shut-in and depressurization technology of water injection well can reduce the layer pressure and reduce the density of the drilling fluid of oil layer, the average density of the drilling fluid of 970 wells in the north No.1 district is 1.44g/cm³, which is lower 0.10g/cm³ than the average 1.54g/cm³ of the primary and secondary encryption.; the average cementing well density is 1.48g/cm³, which is lower 0.10g/cm³ than the average 1.58 g/cm³ for primary and secondary encryption; the drilling cycle is shortened, and the drilling cycle is shortened from 6.2 days to 4.5 days; reduce drilling accidents such as leakage and stuck drills; there are no drilling accidents such as oil well leakage and stuck drills occurred in the drilling construction of 970 wells in the north No.1 district; reducing the impacted water volume of drilling, the average drilling of one well affects about 1100m³ of water injection; improve cementing quality and reduce the number of wells in new and old well casings in the drilling block.

4. Conclusion and Understanding

Through the research on the depressurization adjustment technology test of the water injection well during the drilling process, the drilling range, the wellhead pressure standard, the shut-in depressurization time and the pressurized water injection principle of the main oil layers are determined.

The application of the shut-in depressurization technology of the water injection well in the drilling process has achieved remarkable results: it can effectively control the interlayer pressure difference and greatly improve the cementing quality of the new drilling.

Reasonable arrangement of drilling operation, regional depressurization, pressurized water injection, tracking monitoring and regulation of the oil well's working fluid level can effectively control the layer pressure change speed, reduce the plane pressure difference, prevent the casing damage and reduce the oil layer pollution.

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