Study on Injection-Production Adjustment Technology in Sanduo Oilfield

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Abstract. On the basis of understanding the geological characteristics of low permeability oil fields with scattered sand bodies, this paper studies the water injection policy, response characteristics and the oil fields entering the middle water cut stage since the production. Affected by the scattered underground sand bodies, it is exposed to the influence of low water flooding control degree and less water flooding direction. After water breakthrough, it is difficult to adjust the water well scheme and the formation pressure level is low. In order to alleviate the above contradictions, oil wells are converted to injection, water drive control degree is improved, and formation energy is increased. In order to improve the control degree of sand bodies, several schemes are compared to find out the transfer injection mode suitable for oil fields with scattered sand bodies, increase the proportion of multiple connections and improve the oil recovery ratio.

Keywords: Sand body distribution; Affected characteristics; Middle and late water cut stage; Development contradiction; Transfer note.

1. Introduction

Sand scattered oil field is one of the types of oil fields developed by No.9 Plant, mainly including Px, Ln, Gn and Hw oil fields. Its geological characteristics are scattered sand bodies, small sand bodies and single water drive direction. Especially in the later stage of oil field development to middle water cut, the overall performance is that the water drive direction is single, the adjustment of water well scheme is difficult, the formation pressure drops rapidly, and the plane contradiction is prominent. Therefore, the oil field should adjust the injection-production system, improve the water drive control degree of the oil field, improve the formation energy of the oil field, and alleviate the plane contradiction between layers. In order to explore the effective injection transfer mode of scattered sand body oilfields, the typical Gn Oilfield was selected as an example. By summarizing the knowledge of laws, the effective adjustment mode of injection-production system was optimized, which provided reference for water injection development of similar oilfields.

Gn Oilfield structure is located in the middle of Qijia-Gn sag in the central depression area of Songliao Basin, spanning two secondary structural belts, Qijia-Gn sag and Longhupao terrace. Most of them are lithologic, structural-lithologic reservoirs with good structural inheritance, and are lake-delta sedimentary systems. The target layer is Putaohua oil layer, and the oil-water system is mainly composed of oil and water. In 2012, 250m×250m square reverse nine-point well pattern was put into large-scale development. Putao oil layer has an average porosity of 18.2% and an average permeability of 14.9mD, which belongs to the medium porosity and low permeability reservoir. After the oil field is put into development, in order to maintain the formation pressure, water injection by sand body is implemented. After six months of development, the oil well is gradually getting benefits. The water cut of oil field is rising to 59.5%, entering the middle water cut stage. At present, there is a great difference between the two types of reservoirs in the oilfield, with 69.4% of the main reservoirs and 19.1% of the non-main reservoirs. The rapid increase of water cut in oil field and the big contradiction between layers seriously affect the development effect of oil field. Therefore, research on injection-production adjustment technology in Gn Oilfield is carried out to improve the development effect of Gn Oilfield.

2. Water injection policy and effect characteristics in the early stage of production in Gn Oilfield

The sedimentary microfacies of Gn Oilfield are mainly underwater distributary channel and sheet sand. From the distribution of sub-layer sand bodies, the physical properties of the reservoir are poor and change rapidly in plane, and at the same time, the thickness is thin, the distribution range of single sand bodies in plane is small, and they overlap each other in section or plane. In order to determine the reasonable injection-production ratio and injection allocation intensity in Gn Oilfield, the material balance method was used to calculate the injection-production ratio to maintain the formation pressure in the oilfield.

The original formation pressure of Gn Oilfield is 20.15MPa, the original saturation pressure is 10.07MPa, and the ground saturation pressure difference is 10.08MPa, which belongs to the elastic water pressure driven oilfield. It can be known from the material balance equation and the high-pressure physical property relationship between oil and water:

$$N_pB_o + W_pB_w = NC_eB_{oi}P + W_iB_w \quad (1)$$

Derivating the time derivation yields the following formula:

$$q_oB_o + qW_pB_w - qW_iB_w = (NC_eB_{oi} - (N_pB_oC_o + W_pB_wC_w - W_iC_wB_w))d(\Delta P)/dt \quad (2)$$

Injection-production ratio:

$$\alpha = \frac{qW_i}{qW_p + q_o} \quad (3)$$

The combined water content is:

$$f_w = \frac{qW_p}{qW_p + q_o} \quad (4)$$

Substitute equations (2) and (3) into equation (1) to get:

$$(B_o + (f_w - \alpha)B_w/(1 - f_w))q_o/(NC_eB_{oi}) = d(\Delta P)/dt \quad (5)$$

If the formation pressure is kept constant $\frac{d\Delta P}{dt} = 0$, then:

$$\alpha = \frac{B_o}{B_w} + f_w(1 - \frac{B_o}{B_w}) \quad (6)$$

Block crude oil volume coefficient B_o is 1.2242. Assuming BW = 1.0, the comprehensive water cut after treatment is 20.0%. According to the above formula, the annual injection-production ratio should be about 1.2 when the injection-production relationship is perfect.

According to the determined injection-production ratio and injection allocation intensity, and according to the distribution of sand bodies in Gn Oilfield, water allocation was carried out for sand bodies of different scales.

Table 1 Allocation strength of sand bodies of different scales

Sand body scale	Oil-water well ratio	Considering ineffective water injection-production ratio	Water injection intensity (m3/m.d)
One to one	1:1	1.3	0.8
One to two	2:1	1.4	1.7
Multidirection	3-3.5:1	1.6	3.0

After 6 months of water injection, the oil wells began to take shape one after another, and the affected characteristics were small sand bodies and fast oil wells. Because of the small sand bodies, the oil-water well ratio in local narrow sand bodies was low, the injection-production ratio was high and the oil wells were fast. Statistics show that among the 79 sand bodies with perfect injection and production in the whole region, 24 "one-to-one" sand bodies and 17 "one-to-two" sand bodies are injected and produced. The oil wells with local narrow sand bodies are affected rapidly, "one to one" sand body is affected by 4 wells, "one to two" sand body is affected by 3 wells, accounting for 20.0% of the total number of wells affected.

In the direction of the maximum principal stress, the oil well is affected quickly. The oil wells in Gn Oilfield were put into production by fracturing, and the oil wells were affected quickly in the direction of maximum principal stress. After 4 months of water injection, the oil wells were affected, and the cumulative water injection intensity was low, only 826 m^3/m. Long 34-02 Well Group, measured by passive microseisms, the in-situ stress direction in this area is between 45-70 NE, near the well row direction. Well Longnan 34- Xie01 of this well group has received obvious effect. It was put into production in April 2012, and PI1 (oil layer), PI2 (oil layer) and PI8 (oil-water layer) were perforated. There are two water injection wells around it. The connecting layer PI2 continuously absorbs water, and the cumulative water injection amount is 1856m^3 and the cumulative water injection intensity is 818 m^3/d. The cumulative injection-production ratio of this layer is 4.2 when it is affected by water absorption profile analysis and production split calculation.

w effectiveness and stable liquid production.

According to the stress characteristics of oil wells in Gn Oilfield, the stress intensity, stress time and stress characteristics of different types of oil-water well sand contact relationships are summarized. Among them, "one-to-one" sand body has an effective strength of 400-600m^3/m and an effective time of 4-6 months, which is characterized by quick response and obvious increase in liquid production. The "one-to-two" sand body is 600-800m^3/m, and the effective time is 6-8 months, which is characterized by slow effectiveness and increased liquid production. The "multi-directional water flooding" sand body has an effective strength of 1,000-2,000m^3/m and an effective time of 9-11 months, which is characterized by slow effectiveness and stable liquid production.

3. Main contradictions in water injection development area of Gn oilfield in medium water cut stage

At the initial stage of production, Gn Oilfield implemented water injection by sand body, and maintained high formation pressure. The development effect of the main layer was good, but that of the non-main layer was poor. The contradiction between the two types of layers was prominent. According to statistics, 173 sand bodies developed by water injection, 120 sand bodies were affected, and the affected ratio was 69.4%. There are 47 non-main sand bodies, 9 of which are affected, and the affected ratio is 19.1%. There is a great difference between the two layers in production, and the water cut in the oil field rises rapidly, with the water cut rising rate reaching 4.3%. In order to improve the development effect of Gn Oilfield, Gn Oilfield, which is scattered in development and has a large plane span, is divided into regions according to structure. Different regions have different geological characteristics, development characteristics and contradictions, which is convenient for adjustment and management of regions.

Table 2. Analysis table of producing conditions of different types of oil layers

Category	Number of sand bodies	Number of affected sand bodies	Effect ratio (%)
Main layer	173	120	69.4
Non-main layer	47	9	19.1

3.1 Main contradictions in water injection development area of Gn Oilfield

Contradiction 1: The formation pressure level is low and the proportion of affected wells is low. The original formation pressure of Gn Oilfield is 20.15MPa At present, although the annual injection-production ratio of water injection development zone reaches 1.82, the formation pressure level is low, only 12.38MPa Low formation pressure leads to a low proportion of affected wells in the block, with water injection development for more than eight years. There are 78 affected wells in the oilfield, accounting for 43.3% of comparable wells. The production effect and effect characteristics of Gn Oilfield show that, influenced by factors such as structure, reservoir sandstone and effective thickness, reservoir physical properties, provenance direction and so on, the reservoir-forming conditions of Gu 463-5, Gu 86 and other blocks in Anbu area are favorable, which is conducive to oil and gas enrichment and influenced by western provenance. The width of the channel is 300-600m, the effective thickness of sandstone is low, and the continuity of sand body is good. The sand bodies are relatively contiguous, and the main strata are prominent, with an average porosity of 14.36%, a permeability of 7.69mD and a relatively high regional affected ratio of 52.6%. Reservoir-forming conditions in slope area and syncline area are not conducive to oil and gas accumulation and preservation. Oil and gas reservoirs are formed only by fault shielding in upward dip direction, micro-amplitude structure or lithologic pinchout in upward dip direction, and the scale of oil and gas reservoirs is small. Affected by the northern provenance, the channel width of Gu471 block is 200-500m, the effective thickness of sandstone and sand body is large, the lateral change of sand body is fast, the distribution is scattered, and small-scale sand bodies are the majority. The average porosity in the slope area is 15.17%, the permeability is 17.4mD, and the production effect is poor. The porosity in the syncline area is 13.4%, and the permeability is 2.2mD The oil recovery intensity is 0.28t/m and 0.24t/m, respectively, and the affected ratio is relatively low, 41.3% and 8.0%, respectively.

Contradiction: The contradiction between layers is prominent, and it is difficult to adjust the scheme after water breakthrough in oil wells. The sand bodies in Gn Oilfield are scattered, and the water drive direction is single. Because of the small water drive direction, the average water drive direction of a single well is only 1.8, and the proportion of more than three connections is only 5.1%. Because the larger sand bodies and smaller sand bodies are distributed alternately in the vertical direction. At present, there are 21 water breakthrough wells with 23 layers in Gn Oilfield. From the characteristics of water breakthrough, firstly, affected by the scale of sand bodies, the direction of water flooding in small-scale sand bodies is single, and the injection-production ratio is as high as $4.3m^3/m$, which leads to water breakthrough in oil wells and 5 layers of water wells. Second, large-scale sand bodies are affected by the maximum principal stress of strata, with 11 layers of water breakthrough for oil wells in in-situ stress direction and 7 layers of water breakthrough for oil wells in non-in-situ stress direction. For water-cut rising wells, the surrounding wells have been undergoing scheme adjustment, adopting subdivision, test adjustment and periodic water injection, among which the scheme adjustment effect is obvious in 11 wells, with an effective rate of 52.3%. From the effect of scheme adjustment, controlling water breakthrough in oil wells also limits water injection in large sand bodies, resulting in the decline of liquid supply capacity of oil wells with large sand bodies. Strengthening water injection will easily lead to rapid water breakthrough in oil wells on small-scale sand bodies. Exposing the prominent contradiction between layers and planes, after water breakthrough in oil wells, the contradiction between controlling water cut and improving liquid supply is prominent in well groups, and the interlayer and plane production of blocks is not balanced.

In view of the above two contradictions, in order to improve the injection-production relationship in water injection development zones, increase the multi-directional connection ratio, reduce the ratio of oil to water wells and effectively use the remaining oil, it is necessary to improve the injection-production relationship in time and improve the development effect of oil fields.

Table 3. Water breakthrough in Gn Oilfield

Serial number	Block	Number of wells	Number of water wells seen	See water ratio (%)	Adjust the number of wells	Adjust the number of effective wells	Adjust effective rate (%)
1	Gu 463	50	11	22.0	51	7	38.9
2	Gu 86	29	5	17.2	13	3	60.0
3	Ln03	18	4	22.2	9	3	75.0
4	G 464	26	1	3.8	5		0.0
Total		123	21	17.1	78	13	46.4

4. Design optimization and implementation effect of injection production adjustment technology scheme in Gn Oilfield

In order to control the rapid rising period of water cut in Gn Oilfield and slow down the plane contradiction between layers. Gn Oilfield has designed three schemes for injection transfer, and compared and optimized the three schemes.

4.1 Scheme optimization

Scheme 1, switch to angular wells to form a five-point pattern.

Change the angular wells of oil wells to injection, and adjust them to an area well pattern based on five-point method of 250m×250m, and consider the control range of plane sand bodies and vertical sand bodies at the same time, so as to improve the injection-production relationship of single sand body. Advantages: After injection conversion, a five-point well pattern is formed, which is beneficial to the production of remaining oil, and the recoverable reserves of water flooding are greatly improved. Disadvantages: the utilization of high water-cut wells is less, the loss of effective thickness is greater, and the increase of the ratio of two-way or more connections is lower after injection transfer.

Second, transfer the water injection wells to the side wells to form a well pattern of 45 rows and columns in the northeast.

After the injection, the whole injection-production well pattern is 45 rows and columns in the northeast with a well spacing of 250m×250m m. Advantages: the ratio of two-way connection or above is increased the most, the high water-cut wells are used the most, and the effective thickness loss is the least. Disadvantages: The in-situ stress in the block is near east-west direction. After injection, oil wells and water injection wells are located in the direction of fracture opening, and the fracturing scale of oil wells is limited.

Scheme 3: Transfer injection of side wells of oil wells to form a well pattern of 45 rows in northwest.

After the transfer injection, the whole well pattern is a row well pattern with a well spacing of 250m×250m, 45 to the northwest. After deducting the transfer injection, the wells with poor connectivity between each sublayer and the surrounding oil wells. Advantages: High water-cut wells are widely used, and the ratio of two-way connection or above is greatly increased after injection. Disadvantages: the degree of water flooding control is low; The in-situ stress in the well area is near east-west direction. After injection, the oil well and water injection well are located in the direction of fracture opening, and the fracturing scale of oil well is limited.

Comparing the above three schemes: Scheme 1 has the largest increase in water flooding control degree, with an increase of 2.9 percentage points; The number of sand bodies with or without injection decreased the most, reducing 4 sand bodies with or without injection. The newly added recoverable reserves increased the most, with an increase of 0.96 thousand tons. The ratio of multiple connections in Scheme II increased the most, with an increase of 17.4 percentage points. The loss of effective thickness is the smallest, with a loss of 24.2m. However, there are many poor layers in the converted injection wells, and the water absorption capacity after the converted injection is worse than that in Scheme 1 and Scheme 3. The increase of bidirectional connectivity ratio in Scheme 3 is between Scheme 1 and Scheme 2, which is 17.1 percentage points, with the largest loss thickness and the least new recoverable reserves.

According to the comparative analysis of the above schemes, the first scheme is selected as Gn Oilfield, which needs to be injected into 23 wells. After implementing the adjustment of injection-production system, the injection-production relationship in well area has been further improved. The control degree of water flooding increased from 81.6% to 84.5%, an increase of 2.9 percentage points. The proportion of above two-way connection increased from 34.0% to 47.5%, up by 13.5 percentage points, the newly-added geological reserves of water flooding were 15.9923×10^4t, the newly-added recoverable reserves were 3.1301×10^4t, and the degree of water flooding control was increased by 2.9 percentage points.

Table 4. Adjustment of water drive control degree table of injection-production system in Gn Oilfield

Category	Well pattern form Anti nine point method	Number of oil wells	Number of wells	Oil-water well ratio	Connected proportion (%)			Water drive control degree (%)
					One-way	Two-way	Multi way	
Before transfer	Five point method + irregular	155	68	2.3	47.6	29	5	81.6
After transfer	Well pattern form	136	91	1.5	37	26.9	20.6	84.5
Differential value		-19	23	-0.8	-10.6	-2.1	15.6	2.9

4.2 Implementation and effect of injection production technology adjustment

After the injection-production system is adjusted, in order to ensure the fluid supply capacity of the well area, the formation energy can be restored as soon as possible. At the initial stage, the water injection of new water injection wells should be strengthened, and the old water injection wells should be moderately injected in the unaffected wells, and the affected wells should be controlled to inject water. After the oil wells are gradually affected, the water injection intensity of new and old wells should be further optimized to improve the affected intensity.

Initial injection stage: properly control the water injection in the old direction, strengthen the water injection in the new water injection well, and promote the effectiveness in the new direction. The water injection intensity of the main layer of the new water injection well is 2.7 m3/d.m, that of the non-main layer is 2.2 m3/d.m, and the daily injection allocation of the new transfer well is 120m3, with an injection allocation intensity of 2.6 m3/m.d. Considering the low level of formation pressure and poor liquid supply capacity of oil wells at present, the old water injection well should be properly controlled, and the injection allocation intensity of the old water injection well is 1.5m3/m.d Among them, 15 intervals were stopped by periodic water injection in the direction of water breakthrough, and 22 intervals without water breakthrough were moderately injected with injection allocation intensity of 1.6 m3/d.m, and the injection-production ratio of the converted injection well area was about 2.5 at the initial stage of injection transition. After

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the oil well is effective: the old well implements short-term water injection, and the new well controls the water injection intensity of the main layer to maintain the liquid volume and prevent water breakthrough. The daily injection allocation of old wells is adjusted from 150m3 to 180m3, and the water injection intensity is adjusted from 1.5m3/d · m to 1.8m3/d · M. The daily injection allocation of new wells is adjusted from 120m3 to 90m3, the water injection intensity is adjusted from 2.6m3 / D·m to 1.7m3 / D · m, and the injection production ratio in the well area is controlled at about 2.5. After adjusting the injection intensity of new and old water injection wells through water injection conversion and reasonable matching, the water injection of 69 wells around has been effective, and the average single well has increased by 0.4t.

5. Conclusions

(1) After Gn Oilfield entered the middle water cut stage, the water cut increased rapidly, and the contradiction between layers and planes was prominent. Affected by the small scale and scattered development of sand bodies, the well pattern has a low degree of control over sand bodies, so it is necessary to implement injection-production adjustment to improve the development effect of oil fields.
(2) Through multiple sets of comparisons, the scheme with the highest degree of water flooding control and the highest water flooding reserve is optimized.
(3) The flexible injection mode of "five points plus irregular" can improve the control degree of water flooding to the greatest extent, and it is an effective way to adjust the injection-production system of scattered sand bodies oilfields.

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