Optimization and Adjustment Method of Well Pattern in Three Types of Reservoirs in Ultra-high Water Cut Stage

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Abstract. The well pattern development effect of the three types of reservoirs that have entered the late stage of ultra-high water cut is gradually getting worse, and the inefficient and ineffective wells are gradually increasing. It is necessary to optimize and adjust the well pattern of layer series to improve the development effect. According to the current well pattern, this paper studies the reservoir development, the development status of different well patterns and the adaptability of layer series well pattern combination, and gives the well pattern adjustment methods of three types of reservoirs in the later stage of high water cut in different blocks. This paper summarizes three types of well pattern optimization adjustment methods for three types of reservoirs: 1. For the problems of large well pattern spacing and low control degree in some blocks, infill adjustment is implemented to reduce well spacing; 2. To solve the problems that the adjusted thickness of Class III oil layers in some blocks decreases with the return of Class II oil layers, the original two to three sets of well patterns are mined, and the well spacing is large, and the mining intervals are crossed, the layer series well patterns are merged to improve the injection-production relationship with each other and reduce the well spacing; It is the problem of small well spacing, rapid increase of water cut and small adjustment room of three types of oil layers in some blocks, and well pattern splitting is implemented. Combining with the actual situation, this paper gives the well pattern adjustment modes of three types of oil layers in different blocks at the later stage of high water cut, which has strong guiding significance for the future adjustment of development zones.

Keywords: Three types of oil layers, High water content, Well pattern adjustment.

1. Introduction

In the process of oilfield development, in order to reduce interlayer interference and improve development effect, reservoir classification development is carried out. The well pattern adjustment objects of class III reservoirs in the block are mainly thin and poor reservoirs in Gaotaizi reservoir, Sartu reservoir and PU2 reservoir. The well patterns of three types of oil reservoirs mainly include secondary infill well pattern, tertiary infill well pattern and Gaotai sub well pattern. With the oilfield development entering the late stage of ultra-high water cut, the current well pattern development mode of three types of reservoirs no longer meets the development needs. There are three main problems: first, the 300m inverse nine point method area well pattern injection production well spacing of Gaotaizi reservoir in some blocks is large, the degree of control is low, and the ratio of injection production wells is low; Second, in Gaotaizi oil layer of some blocks, the well spacing of 106m five-point method area is small, the water cut rises rapidly, and adjustment is difficult. It is because the well pattern of Sapu Class III oil layer in some blocks is matched with tertiary oil recovery plugging of Class II oil layer, the adjusted thickness of well pattern gradually decreases, and the number of inefficient and ineffective wells increases, which is difficult to meet the development needs. In order to improve oil recovery and oil layer control, it is necessary to study the adjustment of well pattern of layer series.

2. Necessity of well pattern adjustment in three types of reservoirs

2.1 Gaotaizi 300m anti-nine-point method area well spacing is too large, and the degree of control is low

2.1.1 Gaotaizi oil layer has large injection-production well spacing and low overall production degree

Gaotaizi reservoir in block a is developed with a set of inverse nine point area well pattern. The injection production well spacing is 300m. Although the production

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condition of Gaotaizi reservoir has been improved through fine layered water injection in recent years, the production degree is still relatively low, and the water absorption thickness of the reservoir is less than 70%, which is more than 10 percentage points lower than that of 175m ~ 106m well spacing in other blocks. Therefore, it is necessary to further reduce the development well spacing, reduce the starting pressure of poor formation and improve the production condition of the reservoir.

Table 1 Statistical Table of Basic Situation of Gaotaizi Well Pattern in Block A

Well pattern	Well arrangement mode	Injection production well spacing (m)	Adjustment and stone (m)	Effective adjustment (m)	Oil well (well)	Water well	Oil water well number ratio	Average daily liquid production of single well (T)	Average daily oil production per well (T)	Water content (%)
Gaotaizi	Antinine	300	54.7	20.1	85	39	2.2	29.3	3.3	88.7

2.1.2 Anti-nine-point well pattern has high oil-water well ratio and low multi-directional control degree

The ratio of oil to water wells in the 300m inverted 9-point well pattern of Gaotaizi oil layer in Block A is on the high side, and the water injection of wells in the later stage of high water cut can not meet the development demand, resulting in low formation pressure. In addition, the multi-directional control degree of water flooding in the existing well pattern is low, mainly one-way and two-way communication, with three-way and above oil layers accounting for only about 25%.

Table 2 Statistics of water drive control degree of Gaotaizi reservoir in block a

Oil layer	Type	Control degree (%)					
		One-way	Two-way	Three directions	Four way and above	Three way and above	Total
Senior one group	≥2m	34.9	39.8	14.5	4.8	19.3	94.0
	2~1m	28.6	41.0	21.7	5.0	26.7	96.3
	1~0.5m	26.4	41.2	18.8	8.4	27.2	94.8
	< 0.5m	26.9	43.3	17.0	7.4	24.4	94.6
	Off balance sheet	35.5	38.1	15.3	4.6	20.0	93.5
Senior 2 group	≥2m	13.0	43.5	28.3	10.9	39.1	95.7
	2~1m	22.9	42.3	22.9	9.0	31.9	97.1
	1~0.5m	23.5	43.3	18.6	8.9	27.5	94.4
	< 0.5m	24.5	44.2	17.0	7.8	24.8	93.4
	Off balance sheet	34.3	32.2	12.0	3.0	15.0	81.5

2.2 Three types of oil layers with 106m five-point method area have high water content in well pattern and little room for adjustment

There are two sets of well patterns in Gaotaizi of block B, one set of 300m inverse nine point method area well pattern to exploit gao1 and gao2 oil reservoirs, and another set of 106m five point method area well pattern to exploit Gao3 and gao4 oil reservoirs. Among them, the 106m five point area well pattern is designed, and the polymer surface agent is used for tertiary oil recovery in the later stage. At present, the average daily liquid production of single well in group 1 and group 2 of Gao is 61.8t, the daily oil production is 2.4t, and the water content is 96.1%. The average daily liquid production of single well in group 3 and group 4 of Gao is 60.6t, the daily oil production is 1.8T, and the water content is 97.1%.

Table 3 Basic Statistics of Gaotaizi Well Pattern in Block B

Well pattern	Well arrangement mode	Injection production well spacing (m)	Adjustment and stone (m)	Effective adjustment (m)	Oil well (well)	Water well	Average daily liquid production of single well (T)	Average daily oil production per well (T)	Water content (%)
Gao Yier	Anti-nine point method Five point method	300	50.0	19.3	56	40	1.4	61.8	2.4	96.1
Senior three and senior four		106	46.7	10.4	401	350	1.1	60.6	1.8	97.1

At present, the water content of 106m five point well pattern in group 3 and group 4 of Gao has reached a high level, but there is no tertiary oil recovery plan in the near future. For water drive, 106m well spacing is too small, which is easy to form dominant water channel and has little room for adjustment. Through comparison, it is found that the water cut rise rate of 106m well spacing well pattern is significantly higher than that of 300m well pattern.

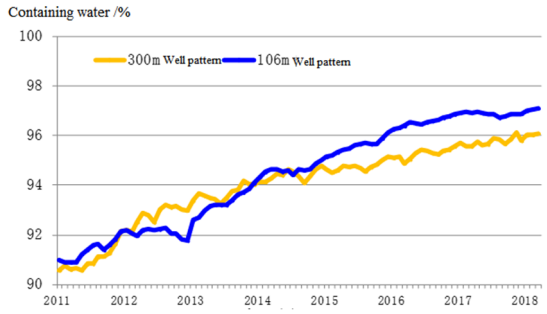

Fig. 1 B Water cut change curve of Gaotaizi well pattern in block B

At present, the proportion of wells with water content greater than 98% in 106m well pattern reaches 51.9%, the proportion of wells with daily oil production less than 1t reaches 32.7%, and there are many low efficiency wells.

Table 4 Statistics of water cut classification of zqxb Gaotai sub well pattern

Well pattern	Proportion of wells (%)				
	98% ≤fw	96%≤fw < 98%	94%≤fw < 96%	90%≤fw < 94%	fw≤ 90%
Gao yier	18.4	44.9	8.2	16.3	12.2
Senior four	51.9	26.1	11.0	6.3	4.7

Table 5 Statistics of daily oil production classification of Gaotaizi well pattern in Block B

Well pattern	Proportion of wells (%)				
	Q oil ≤ 1	1 ≤ Q oil < 2	2 ≤ Q oil < 3	3 ≤ Q oil < 4	4 ≤ Q oil
Gao yier	16.3	28.6	24.5	12.2	18.4
Senior four	32.7	38.7	11.0	9.6	8.0

2.3 C block secondary infilling and tertiary infilling well patterns with tertiary oil recovery plugging have small adjusted thickness

Sabu class III oil layer in Block C mainly includes secondary infill and tertiary infill well pattern mining. The two sets of well patterns are 250m inverse nine point area well patterns. The three types of oil reservoirs in SA + Portugal group II are exploited, which has the problems

of cross adjustment objects and uneven injection production well spacing.

Table 6 Statistical table of basic situation before adjustment of well pattern of secondary and tertiary infilling in Block C (201508)

Well pattern	Mining object	Well arrangement mode	Injection production well spacing (m)	Oil well (well)	Water well	Oil water well number ratio	Average daily liquid production of single well (T)	Average daily oil production per well (T)	Water content (%)
Secondary encryption	SA + Pu 2 reservoir	Anti nine	250	93	33	2.8	40.7	2.4	94.0
Triple encryption	Sapucha reservoir	Anti nine	250	109	44	2.5	31.4	1.8	94.2

After the tertiary oil recovery of saii10-saii10 of class II oil layer, it returns to saii1-9 for tertiary oil recovery. In order to reduce the interference of water polymer flooding and avoid affecting the development effect of polymer flooding, it is necessary to block the corresponding horizon of water flooding well pattern. After blocking, the average effective perforation thickness of secondary and tertiary infill is 6.3m.

Table 7 Statistical table of the change of plugging thickness of well pattern of secondary infilling and tertiary infilling in Block C

Well pattern	Full well perforation thickness		Residual thickness of plugging saii10 - III 10		Residual thickness of plug II 1-9	
	Sand stone	Effective	Sand stone	Effective	Sand stone	Effective
Secondary encryption	27.0	10.7	22.0	8.6	19.0	6.7
Triple encryption	17.9	6.7	17.0	6.5	15.9	6.0
Total	21.9	8.5	19.2	7.4	17.2	6.3

After plugging Sa ii 1-9 oil layer, the proportion of wells with effective perforation thickness less than 4m in the second and third infill pattern reached 28%, which affected the development effect. There is no need for independent development of casing pattern, and all of them need to be supplemented with adjustment objects.

Table 8 Statistical classification of thickness adjustment for two blocks and three infilling wells in block C

Well pattern	Proportion of wells (%)				
	H < 2m	2m≤H < 4m	4m≤H < 6m	6m≤H < 8m	8m ≤H
Secondary encryption	4.7	18.8	30.6	18.8	27.1
Triple encryption	8.7	22.6	24.3	25.2	19.1
Total	7.0	21.0	27.0	22.5	22.5

3. Well pattern adjustment method for three types of reservoirs

3.1 Well pattern adjustment principle of class III reservoir

In order to make the well pattern of the three types of oil layers achieve reasonable exploitation well spacing and improve the control degree, so as to improve the development effect of the three types of oil layers. Combined with the present situation of block development well pattern and oil production, the adjustment principles of three types of oil layer well pattern are determined:

First, make full use of the old well pattern and adjust the appropriate well spacing;

Second, the adjusted well pattern must be a regular area well pattern;

Third, the adjustment object should have a certain thickness and reserve basis to ensure the adjustment effect.

3.2 Well pattern adjustment method of three types of oil layers

3.2.1 Use 300m inverse nine point method area well pattern to densify into 150m five point method area well pattern

Gaotaizi in block a uses the old well pattern, adding wells between wells and rows to form a 150m five point area well pattern.

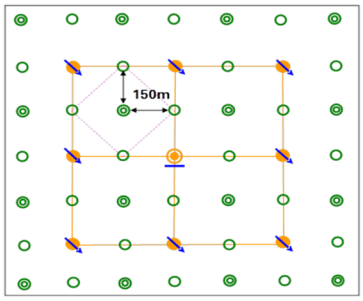

Fig. 2 Schematic diagram of well pattern infilling of Gaotai sub well in block a

3.2.2 Divide the 106m five-point method area well pattern into two sets of 150m five-point method area well pattern.

Gaotaizi in Block B forms a set of oil and water wells with a 106m five point method area well pattern into a 150m five point method area well pattern. The well pattern composed of oil wells exploits Gao 3 and 4 groups of oil layers, and the well pattern composed of water wells exploits Gao 2 groups, which is equivalent to densifying Gao 2 groups of oil layers. The original well pattern of group Gao 1 and 2 blocks group Gao 2, forming 3 sets of well patterns and 3 sets of strata.

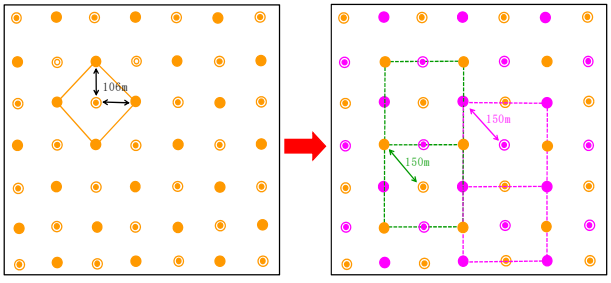

Fig. 3 Schematic diagram of zqxb Gaotaizi well pattern splitting

3.2.3 Combine the twice encrypted and the third encrypted 250m anti-nine-point method area well pattern into a set of 175m inclined array well pattern.

The secondary infill and tertiary infill well patterns in Block C are 250m inverse nine point method area well patterns, and are staggered by half a well spacing. The converted injection angle wells can be combined into 175m inclined row and column well patterns, and the injection production relationship between Kaisa group I and Portugal group II can be improved.

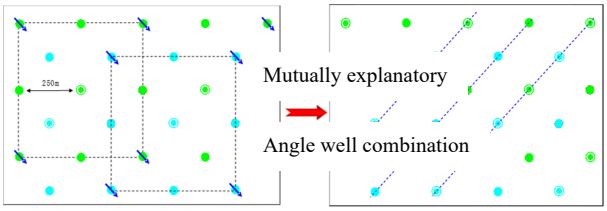

Fig. 4 Schematic diagram of BYXB secondary and tertiary infill well pattern combination

4. Analysis of adjustment effect of three types of oil layers

4.1 Well pattern infill EOR

According to the mathematical model prediction, the pre-production recovery rate of the infill adjustment well pattern in Gaotaizi oil layer in Block A is 32.6%. When the original well pattern is waterflooded to the comprehensive water cut of 98%, the final recovery rate of waterflooding is 39.2%, that of 150m infill well pattern is 42.1%, and that of infill well pattern is increased by 2.9 percentage points. The geological reserves of Gaotaizi oil layer with infill well pattern are adjusted to 3720.3×104t, and the recoverable reserves are increased by 107.9×104t with infill well pattern. According to the 2018 economic benefit evaluation system, the after-tax financial internal rate of return is 11.7%, and the economic benefit is good.

4.2 Well pattern splitting to increase the recovery degree of Gaotaizi reservoir

The permeability of Gaotaizi reservoir in Block B is mainly 50 ~ 150 × 10-3 μ Within m2, the effective permeability is 50 ~ 150 according to the relationship between water drive injection production well spacing and recovery factor of oil reservoirs with different permeability × 10-3 μ M2 oil layer, when the well spacing is less than 150m, the recovery degree decreases little with the increase of well spacing. Therefore, the well pattern of 106m five point method area in zqxb Gaosan and Gaosi Group oil layer is divided into 150m five point method area well pattern, which has little impact on the final recovery of Gaosan and Gaosi Group oil layer, but it can change the water injection flow line and expand the wave and volume. For gao2 reservoir, it is equivalent to densifying 300m inverse nine point method area well pattern into 150m five point method area well pattern, and the recovery factor increases greatly.

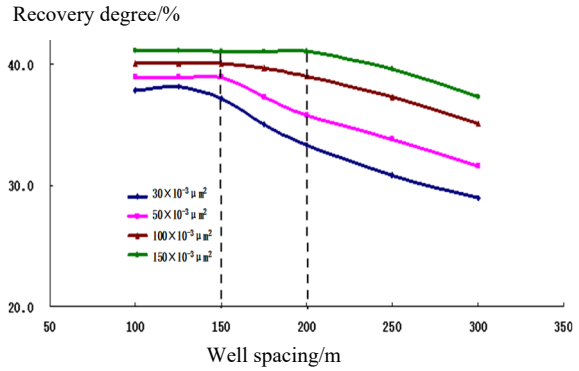

Fig. 5 Relationship between injection-production well spacing and recovery factor of oil layers with different permeability

4.3 The control degree will increase after the well pattern combination improves the injection-production relationship with each other

After the combination of secondary infill and tertiary infill well pattern in Block C, the effective thickness of well pattern adjustment reaches 10.4m, an increase of 4.1m compared with that after plugging.

Table 9 Statistical table of patching hole thickness of BYXB secondary and tertiary infill well pattern

Well pattern	Full well perforation thickness		Residual thickness after plugging		Thickness after patching	
	Sand stone	Effective	Sand stone	Effective	Sand stone	Effective
C Triple encryption	27.0	10.7	19.0	6.7	26.7	10.2
Total	17.9	6.7	15.9	6.0	25.0	10.5
	21.9	8.5	17.2	6.3	25.7	10.4

After the well pattern combination improves the injection production relationship with each other, the average daily oil increase of a single well is 0.8t.

Table 10 Comparison of production situation before and after the second and third infill well pattern adjustment of ByXB

Well pattern	Before adjustment (201508)					After adjustment (201612)				
	Oil well (well)	Well opening	Daily liquid production of single well (T)	Daily oil production of single well (T)	Water content (%)	Oil well (well)	Well opening	Daily liquid production of single well (T)	Daily oil production of single well (T)	Water content (%)
Secondary adjustment well	93	87	40.73	2.4	94.09	68	63	52.95	3.2	93.99
Tertiary adjustment well	109	101	31.435	1.8	94.29	84	79	54.353	2.7	95.09
Total	202	188	72.17	2.1	94.1	152	142	107.3	2.9	94.5

The multidirectional connectivity ratio of group Sa 1 and group Pu 2 before well pattern combination is 46.0% and 32.7%. After well pattern combination hole patching, the control degree of group Sa 1 and group Pu 2 is greatly improved, especially the multidirectional connectivity ratio is increased by 29.0% and 39.0% respectively.

Table 11 Statistical table of control degree before adjustment of injection-production system

Interval	Unidirectional connectivity (%)			Bidirectional connectivity (%)			Multidirectional connectivity (%)			Total (%)		
	Number of layers	Sandstone	Effective	Number of layers	Sandstone	Effective	Number of layers	Sandstone	Effective	Number of layers	Sandstone	Effective
Sa Yi Group	18.2	19.3	19.1	27.6	27.8	29	48.3	47.3	46	94.1	94.4	94.1
Portuguese group II	24.6	24.7	25.2	28.1	28.3	28.8	37.5	36.1	32.7	90.2	89.1	86.8

Table 12 Statistical table of adjusted control degree of injection-production system

Layer segment	Unidirectional connectivity (%)			Bidirectional connection (%)			Multidirectional connectivity (%)			Total (%)		
	Number of pilies	Malmstone	Effective	Number of pilies	Malmstone	Effective	Number of pilies	Malmstone	Effective	Number of pilies	Malmstone	Effective
Salzu Pu2zu	19.7	18.9	20.4	19.9	20	18.1	446	48	48.2	84.1	86.9	86.7
	28.8	29.5	28.8	24.1	25.8	24.3	215	20.4	19.8	74.4	75.7	72.9

Table 13 Statistics of control degree after hole patching

Interval	Unidirectional connectivity (%)			Bidirectional connection (%)			Multidirectional connectivity (%)			Total (%)		
	Number of layers	Malmstone	Effective	Number of layers	Malmstone	Effective	Number of layers	Malmstone	Effective	Number of layers	Malmstone	Effective
Sa Yi Group	7.7	6.3	6.6	17.6	17.9	17.3	73.6	75	75.4	98.9	99.1	99.3
Portuguese group II	7.7	8	9.2	13.8	14.5	14	75.7	73.9	71.7	97.2	96.4	94.9

5. Conclusion

(1) With the oil field entering the later stage of ultra-high water cut, the contradiction between the well patterns of the original three types of oil layers is getting bigger and bigger, which needs to be adjusted.
(2) According to the actual situation of well pattern in the block, three types of well pattern adjustment methods of oil layer can be adopted, including well pattern encryption, well pattern splitting and well pattern combination.
(3) Three types of oil layer well pattern adjustment have great potential in oilfield application.

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