

Study of Well Pattern Optimization Techniques in High Dip Angle Fault Block Reservoir

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Abstract. The study area is a narrow complex fault block reservoir, which is characterized by large strata dip, large reservoir thickness and strong interlayer heterogeneity. At the initial stage of development, a set of stratigraphic series is adopted for development. At present, there are problems of unbalanced utilization between layers and rapid rise of water cut. In order to meet the needs of overseas oilfields to improve the oil production rate during the development period, this paper analyses the geological and development affecting factors of high productivity wells through the study of fine reservoir geological body, the quantitative characterization and distribution of remaining oil. Moreover, the optimization of the development pattern of small well spacing is studied. Through changing the development mode, adjusting the well pattern layer series, and deploying a set of well pattern in the fault area and enrichment area with remaining oil inter well in three dimensions to develop the oil layers with poor production of old wells, stereoscopic potential tapping can be attained. The method of layer by layer upward development is adopted, and the production is carried out in batches vertically, so as to reduce the contradiction between layers and increase the degree of reserve production, improve the oil production rate and recovery degree during the development period of the oilfield finally.

Keywords: High dip angle fault block、 Potential exploitation in fault area, Well pattern optimization、 Upward development.

1. Introduction

For the development of heterogeneous multi-layer reservoirs, domestic oilfields such as Daqing and Shengli oil field generally adopt the development mode of dividing multiple layers. Some fault block oilfields with small reservoir scale and complex structure, such as Chenbao and Anfeng oilfield in Jiangsu oilfield, adopt a set of well pattern and return layer by layer development mode. The development of foreign oilfields is limited by the contract term and economic conditions, Block A adopts a set of well pattern to development, and it is predicted that the degree of reserve recovery is only 11% during the development period. In order to fully exploit the reserves of non-main oil reservoirs in the lower part of the high part of the fault area, reduce interlayer interference, and take more and faster oil to maximize economic benefits during the contract period, it is necessary to study the well pattern optimization technology to further optimize and improve the well pattern.

2. Main geological features

The dip angle of fault block B in block A is large, with an average of 25 °. The main oil-bearing zones are I and II oil group of Tongbomiao formations. Fault Block B develops fan-delta front facies deposition, which mainly consists of underwater distributary channel, sheet sand, interchannel and lacustrine mud microfacies. Reservoir is mainly tuffaceous fine sandstone, and secondly tuffaceous glutenite. On the plane, the whole area is dominated by sandstone, and the mixed area of sandstone and glutenite is mainly developed at the edge of fault block. The effective thickness near the main control fault is large, averaging 69.1m. The average effective thickness of oil reservoir is 48.5m, the average porosity is 16.1%, the average air permeability is 50.1mD, the coefficient of variation between layers is 1.7, and the heterogeneity is strong (Table 1, Table 2) .

Table 1 Pore roar distribution data of rock samples

Hole radius of roar (μm)	<1	1.0~2.0	2.0~4.0	>4.0
The proportion (%)	48.2	8.4	12	31.4

Table 2 Permeability distribution data of rock samples

Permeability (mD)	0.1~1	1~10	10~50	≥ 50
Sample percentage (%)	44.8	13.4	15.1	26.7

3. Development present situation

Fault block B was put into production in December 2006, using zigzag well pattern, 160 ~ 260m well spacing development. By the end of 2021, there were 49 production wells in total, with an average daily oil production of 6.0t/d, and the cumulative oil production was $113.47 \times 10^4 \text{t}$, the composite water cut was 75%, recovery degree was 8.85%. The oil production in 2021 was $8.13 \times 10^4 \text{t}$ and accounting for 32% of the output of block A, the oil production rate was 0.64%. There were 28 water wells, with an average daily water injection of $67.9 \text{m}^3/\text{d}$ and a cumulative water injection of $384.82 \times 10^4 \text{m}^3$, and the cumulative injection production ratio was 1.67 (Table 3).

Table 3 Development data sheet of block A

Oil well		Water well		Average daily oil (t/d)	Water cut (%)	The cumulative oil production (10 ⁴)	Mean daily water injection (m ³ /d)	Cumulative injection-production ratio	Production rate (%)	Recovery degree (%)
T	O	T	O							
he	pe	he	pe	A	W	Th	Me	Cu	Pro	Re
tot	on	tot	on	ve	at	e	an	mul	duc	co
al	n	al	n	ra	er	cu	dai	ativ	tion	ver
nu	w	nu	w	ge	cu	lati	ly	e	n	y
m	ell	m	ell	da	t	ve	wa	in	rate	de
be	nu	be	nu	ily	(	oil	ter	je	(	gre
r	m	r	m	oil	%)	pro	in	ctio	%)	e
of	be	of	be	(	)	duc	ec	n-	%)	(
W	r	W	r	t/d	)	tion	ion	pro	%)	(
ell		ell		)		n	(	duc)	%)
s		s		)		(10 ⁴)	m ³ /d)	tion)
								ratio		
49	40	28	27	6.0	75.0	113.46	67.9	1.67	0.64	8.85

4. Main development contradiction

The overall development effect of fault block B is good, but there are still two problems. First, water cut rises rapidly in some well area, oil wells has high yield liquid and high water cut, the proportion of wells with water cut of more than 90% is 32.7%. Second, some well areas separated from the water well had low liquid production in the high part of the structure and had low formation energy. There are still 24.5% of oil production wells with daily liquid production of less than 10t/d.

5. Study of Well Pattern Optimization Techniques

5.1 Re-understanding of drilling high yield well

(1) Brittle reservoir in footwall of antithetic normal fault is a favorable potential area

The sand-stratum ratio of well G1 located in the high part of the structure was 0.84, and the daily production of oil was 93.8 t/d at the early stage. Seismic data showed that the reservoir near the brittle fault had low mud content, and the hard rock showed brittle failure, with clear and immaterial changes. The reconstruction near the fault was sufficient, and high-quality reservoirs were easy to develop in the high part of the brittle fault. The brittle fault-controlled reservoir with sand ground ratio above 0.8 are the main potential areas in fault block B of block A (FIG. 1).

(2) The reserves in the lower part of the high part of the fault area are not developed, which is a potential area for the enrichment of remaining oil

In 2019, three new Wells were drilled along the fault edge, which were located in the area with large effective thickness at the high part of the structure. The daily oil production of well G1 was 93.8 t/d, the daily oil production of G2 was 4 t/d, the daily oil production of G3 was 10 t/d (Table 4 and Figure 2).

Table 4 Production information of wells in high parts of structure

Well name	G1	G2	G3
effective thickness (m)	104.8	64.3	31
daily oil output (t/d)	93.8	4	10

5.2 Study of remaining oil distribution

(1) Vertical distribution characteristics of remaining oil
The remaining oil is enriched in low permeability reservoirs with poor physical properties because of strong heterogeneity, the vertical permeability distribution difference, and the interlayer difference.

(2) Distribution characteristics of remaining oil on the plane

There are three main types of plane remaining oil distribution:

a. Remaining oil controlled by structure. The remaining oil is relatively enriched in the high part of the fault area, the high point of microstructure or the corner of the fault and the areas with poor water flooding effect.

b. Remaining oil formed by imperfect injection production well pattern. Due to the large strata dip, the water injection wells in this well area are mainly distributed in the low part of the structure at the edge of the fault block. There are no water injection wells in some well areas, and the development degree of oil reservoir is low.

c. Remaining oil between adjacent production wells. Dead oil areas are formed in some well areas with large well spacing, small oil drainage radius and relatively low production degree between wells.

5.3 Well pattern optimization design

The principle of well pattern optimization is determined according to the reservoir development conditions and remaining oil distribution law.

a. Considering the production degree of oil layer, a set of well pattern development with small well spacing is adopted, and the upward development mode is used.

b. Referring to the well pattern form of the developed area, the potential digging wells in the fault area shall be flexibly deployed according to the fault development and the location of surrounding wells. The internal supplementary wells are flexibly deployed with triangular well pattern, and the well spacing is 140 ~ 170m.

c. In order to improve the drilling rate of oil reservoirs at the fault edge, the fault tapping wells are designed as high angle deviated wells along the section, and the other wells are vertical wells.

(1)Exploiting potential in fault block to improve oil recovery rate

The production profile and injection profile of adjacent wells in the well layout area shows that the liquid production and water absorption of the upper main layers T I 17, T II 20, T II 25 are good, and the overall production of the lower oil layer is poor. Therefore, a set of well pattern with small well spacing is deployed to give priority to the development of II and III reservoirs with poor production in the lower part, so as to weaken the interlayer contradiction and improve the reservoir producing degree. At the same time, according to the liquid production, water absorption and actual drilling situation, avoid the water flooded layer, and employ the upper main oil layer in the later stage to control the rising speed of water cut and improve the recovery degree.

Table 5 The scheme of upward development mode in fault block

Layer s	Predicted effective thickness (m)									
	A1	Upward development t plan	A2	Upward development t plan	A3	Upward development t plan	A4	Upward development t plan	A5	Upward development t plan
T I 17	1.3		1.0		1.0		2.6		4.1	
T I 18	4.6		0.6		0.6		1.6		5.9	
T II 19	2.5	2	2.2	2	2.3		1.7		0.8	
T II 20	2.9		2.2		1.2		2.3	2	1.3	2
T II 21	2.3		2.1		2.0		3.0		1.3	
T II 22	5.1		2.5		2.1		3.4		3.1	
T II 23	5.6		3.4		5.0	1	3.8	flooding to avoid perforation	3.0	flooding to avoid perforation
T II 24	4.1	1	6.0		10.0		4.9		3.7	flooding to avoid perforation
T II 25	7.7		7.4	1	6.6	flooding to avoid perforation	6.8	1	4.0	
T II 26	6.4		6.1		water		8.8		4.4	1
T II 27	water		4.0		water		water		6.8	
T II 28	water		water		water		water		4.8	
T II 29	water		water		water		water		water	
T II 30	water		water		water		water		water	
T II 31	water		water		water		water		water	

(2)Exploiting potential of remaining oil enrichment area in the high part of fault block

A40 well area has high structural position, thick oil layer and high oil column height, and the lower II and III oil layers are developed with low production degree. It is a

potential tapping area for the remaining oil at the edge of the fault in the high part of the fault block. Through upward development, give priority to the development of oil reservoirs with low production degree in the lower part, shoot out the upper layer in the later stage, realize full layer production and increase the production degree of reserves.

Table 6 The scheme of upward development mode in high part of fault block

Layers	Predicted effective thickness (m)					
	A6	Upward development plan	A7	Upward development plan	A8	Upward development plan
T I 17	2.8	2	6.1	2	8.3	2
T I 18	1.5		6.0		7.5	
T II 19	2.6		6.3		2.2	
T II 20	2.7		0.5		1.3	
T II 21	4.4	1	2.7	1	2.3	1
T II 22	4.3		2.7		4.0	
T II 23	5.3		5.5		3.5	
T II 24	9.0		4.9		4.6	
T II 25	water		2.4		4.8	
T II 26	water		1.8		1.3	
T II 27	water		5.0		1.6	
T II 28	water		4.8		3.7	
T II 29	water		2.8		2.0	
T II 30	water		water		2.4	
T II 31	water		water		water	

(3) Exploiting potential of remaining oil enrichment area between water injection wells

The wells located near the oil-water contact in the low part of the structure, the formation energy is sufficient. Although the thickness of the oil layer is reduced, it still has a certain productivity in the initial stage. These wells can be bailed out first, and then used as injection wells after the water cut increases in the later stage, forming linear water injection with edge wells to supplement formation energy.

A total of ten supplementary wells were designed, among which five wells were designed in order to reduce well spacing to develop II and III oil layers and improve oil recovery rate. Three Wells were designed to exploit potential of the remaining oil enrichment area at the fault edge of the high part of the fault block. Two wells are designed to exploit potential of remaining oil enrichment area between injection wells.

6. Conclusions and Cognition

(1)Fault block B in block A has large formation dip angle, large reservoir thickness and strong interlayer heterogeneity. At the initial stage of development, restricted by economic conditions, a set of well pattern is adopted, resulting in the problems of unbalanced interlayer production, rapid rise of water cut in some well areas and insufficient formation energy in some well areas. (2) By analyzing the geological and development factors affecting high-yield wells, and based on the study of the distribution law of remaining oil, ten wells are optimized

to exploit the potential remaining oil in fault area and well area with imperfect injection production relation.

(3) The layer by layer upward development method can effectively exploit the lower II and III reservoirs, which is conducive to alleviate the heterogeneous contradiction between layers, control the rising speed of water cut and increase the degree of reservoir production.

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