Practice and cognition of effective water-flooding development mode in Gaotaizi block of ultra-low permeability reservoir

Ping Cui

No.9 Oil Production Plant, Daqing Oilfield Co.Ltd., PetroChina 163000 China

Abstract. During nearly 25 years of water injection development in Gaotaizi reservoir of LHP oilfield, due to poor reservoir physical properties, poor adaptability of well pattern and difficulty in establishing effective displacement between oil and water Wells, linear water injection, infill adjustment and refracturing tests have been carried out successively. Although certain effects have been seen, the effects are short and unsatisfactory. In this paper, the microscopic pore structure, sensitivity and seepage characteristics of ultra-low permeability high platform reservoir are studied through core laboratory experiments. New technology of nonlinear test and low permeable physical simulation experiment, the research on the rules of the nonlinear characteristics of the reservoir fluid and the characteristics of movable oil through research has been clear about the dragon bubble oilfield high effective displacement distance platform layer, and the new fracturing technology and the development of the technology to adjust the organic combination, the displacement between well and well past into displacement between Wells and joint network, explore the ultra-low permeability reservoir to improve the single well production, new ways to improve the development effect, with the types of low permeability oilfield development effectively.

Key words: Ultra-low permeability;effective displacement; joint network; Development effect.

1. Block overview

1.1 Geological characteristics

The structure of LHP single production Gaotaizi oil layer block is located in the west of Qijia Gulong sag and the north of Longhupao Da'an terrace in the central depression of Songliao basin. It is the first ultra-low permeability oilfield in the western periphery of Changyuan that has been put into development in a large area. The developed oil-bearing area is 41km^2 and the produced geological reserves are 880 × 10^{4}t. The main reservoirs are GⅢ group and GⅣ group, which are characterized by poor reservoir physical properties and small single-layer thickness. The average porosity is 15.3% and the air permeability is 0.5mD, the thickness of perforated sandstone is 13.3m, and the effective thickness is 5.8m. From south to north, the thickness of single layer of oil layer becomes thinner, the number of layers increases, and there is no intensively developed interval. The reservoir lithology is mainly argillaceous siltstone, and the argillaceous content is as high as 23.0%, belonging to a tight reservoir with low porosity, low permeability.

1.2 Development profile

LHP Gaotaizi reservoir block was fractured and put into operation in 1998, and the oil well production decreased rapidly. In 2000, microbial injection, acidizing and plugging removal, repeated fracturing, hydraulic sand blasting perforation and other tests were carried out to reduce water injection pressure. Only 42.6% of the wells were effective, with an average effective period of 3.2 months. The cumulative oil increase of a single well was 78t; In 2001, the infill adjustment test area was opened up in L114-12 well block, with the well spacing reduced from 300m to 150m, and the daily liquid production of infill wells was only 0.32t; In L118-10 well block, in combination with the linear water injection well network from the original well pattern to the water injection flooded angle well, the oil well drainage is densified, the oil well drainage distance and well spacing are reduced to 212m, and the daily liquid production of the densified well is 0.5t; Since 2002, the water injection wells have been gradually inter injected, and the oil production wells have been changed to catch oil, so as to reduce the development cost of the oilfield.

2. Research on effective utilization mode

2.1 Core laboratory study

Through the indoor core test, the micro reservoir characteristics of Gaotaizi reservoir, such as pore structure, fluid and seepage characteristics, sensitivity, etc., are clarified.

The pore structure of LHP Gaotaizi reservoir is mainly composed of small throat, and the contribution of large throat to permeability is large; The permeability is less than 0.5mD, and the average throat radius is less than 1 μm. Permeability 0.5-1mD, throat radius 0.5-1.5 μm; The average permeability of Gaotaizi reservoir is 0.5mD, and the corresponding movable fluid percentage is 30.43%, belonging to low permeability class IV reservoir; The stress damage degree corresponding to permeability of 0.5mD is 21.74%. The core with permeability less than 0.5mD is mainly plastic deformation, and the reservoir as a whole is weakly pressure-sensitive; The two-phase co permeability ranges from 12.7% to 28.5%, and the average final recovery factor is 35.4%; Movable oil mainly comes from the pore space controlled by 0.1~1 μm throat, the two-phase co permeability zone is narrow and the oil displacement efficiency is low; Starting pressure gradient is 0.1685MPa/m.

According to the analysis of five parameter comprehensive evaluation method, LHP Gaotaizi reservoir belongs to low permeability class III reservoir. Compared with Putaohua and Fuyang oil layers, Gaotai sub layer has small throat radius, small percentage of movable fluid, high starting pressure gradient, high clay mineral content and low crude oil viscosity, which makes development difficult.

Table 1. Five parameter comprehensive evaluation results of low permeability reservoir

oil layer	block	permeability (mD)	Average throat half_path (μm)	Percentage of movable fluid (%)	Starting pressure gradient (MPa/m)	Clay mineral content (%)	Crude oil viscosity (mPa•s)
Gaotaizi	LHP	0.5	1.023(III)	30.43(IV)	0.1685(III)	23(IV)	1.40(I)
	QJN	1.18	1.839(III)	42.54(III)	0.0930(II)	10.33(III)	2.30(II)
Putaohua	AN	13.30	2.927(II)	51.70(II)	0.0067(I)	15.50(IV)	5.73(III)
	GLN	3.10	1.948(III)	51.73(II)	0.0240(II)	10.25(II)	2.12(II)
Fuyang	BYCG	2.30	1.987(III)	34.12(IV)	0.0887(II)	15.56(IV)	2.45(II)
	TLH	0.27	0.452(IV)	18.91(IV)	0.2209(III)	12.24(III)	1.74(I)

Calculation of effective driving well spacing by using the formula of effective driving distance in Daqing Peripheral Low Permeability oilfields：

$$L_c = \frac{P_w - P_f - \frac{cn\,\mu\eta}{kh}}{\lambda}$$

λ — Starting pressure gradient,MPa/m； K — permeability， mD； P_w — flowing pressure of water injection well，MPa； P_f —Oil well flowing pressure，MPa； Lc —effective drive well spacing，m； c —unit conversion factor86.4； n —Ratio of row spacing to well spacing, dimensionless； μ — Formation viscosity of crude oil ， mPa.s ； η — Stable liquid production intensity，t/d.m； h —effective thickness，m。

It is calculated that the effective driving well spacing of Gaotai sub layer in LHP single high well area is 149m.

2.2 Network optimization

According to the idea of combining fracture network, due to the reservoir development status, combined with the existing injection production well network and stress direction, optimize the relationship between well network and fracture network, fracture network and sand body configuration, and transform the previous effective displacement between wells into effective displacement between wells and fracture network.

2.2.1 Optimization of large scale molded fracture network in vertical well

According to the direction of maximum principal stress, effective displacement distance and water drive front, the scale of single well fracture pattern is optimized to prevent premature flooding while realizing effective displacement; The designed fracturing half fracture length of the side well is 260m, the micro fracture extension width is 200m, and the displacement well spacing after fracturing is shortened to 85m; The designed fracturing half fracture length of angle well is 300m, the micro fracture extension width is 250m, and the displacement well spacing is shortened to 130m after fracturing.

2.2.2 Optimization of infill horizontal well spacing

According to the reservoir development, combined with the injection production well pattern and stress direction, the matching relationship between well pattern and fracture pattern is optimized, and a personalized perforation and fracturing scheme is prepared to establish effective displacement between fractures and well pattern. There is no perforation within 50m of the water well, the half fracture length of fracturing is 80-260m, and the displacement distance after fracturing is 50-139m, all within the range of effective displacement distance.

In order to ensure sufficient water injection energy at both sides of the horizontal well, the asymmetric diagonal injection mode is adopted to form a zigzag injection production well pattern. 8 wells are designed to be converted into injection. After the conversion, the water wells are reasonably matched with the water injection intensity. The water injection intensity is controlled in the vertical geostress direction, and the water injection intensity is controlled at about 1.0m^3/m.d. the water injection intensity is appropriately enhanced in the parallel geostress direction, and the water injection intensity is about 1.5 m^3/m.d.

According to different reservoir conditions, different methods are adopted for test exploration. Vertical well fracture pattern fracturing is adopted in the reservoir with a large number of layers and poor continuity (L118 test area). Horizontal well infill and through layer fracturing tests are carried out in the stable sheet sand reservoir with prominent development in the main layer (L130 well area), so as to seek an economic and effective development method for different types of reservoirs.

3. Implementation effect and understanding

3.1 Vertical well fracture pattern fracturing

Five wells in L118 well cluster of longhupaogaotai sub layer are selected for vertical well fracture pattern fracturing test. The average fracturing fluid consumption of a single well is 3641m^3 and sand addition is 96m^3. After fracturing, the daily oil increase of a single well is 3.8t, and the cumulative oil increase of a single well is 2597t.

The following understandings have been obtained for vertical well fracture pattern fracturing:

First,a certain fracture network scale has been formed, and large-scale reservoir reconstruction has been realized. From the process of downhole microseismic real-time monitoring, during the fracturing process, the slippery water produced obvious main fractures in the first stage, and then the fractures were mainly generated in the fracture network in the clean water and sand adding stages. The internal volume of the early fracture grid was transformed. According to the underground microseismic monitoring results, the actual fracture network is 308-534m long, 63-93m wide and 66-83m high.

Second, reservoir production has been significantly improved, single well production has been increased, and oil production has been significantly increased. At the initial stage after fracturing, the thickness production ratio of sandstone in the whole well is increased from 62.9% to 97.0%, and the production degree of reservoirs with different thickness is improved; The output ratio of sandstone thickness of reservoir with effective thickness <0.5m has increased from 53.7% to 100%, and the daily fluid increase accounts for 39.8% of the whole well. The fluid increase effect is obvious. After 6 months, the output of thin and poor layers became worse, and the output ratio of sandstone thickness of reservoir with effective thickness <0.5m decreased from 100% to 18.5%; The liquid production of the main formation is stable, and the liquid production proportion increases. The liquid production proportion of GШ3 accounts for about 50% of the whole well. Compared with conventional fracturing, the daily oil increase of a single well at the initial stage of fracture pattern fracturing is 3.8t, which is 2.5 times that of conventional fracturing.

Third, effective displacement has not been established, and the liquid supply capacity is poor. From the water well, the injection pressure is stable at 22.5MPa, which is equal to the pump pressure. The apparent water absorption index is reduced from 1.07m^3/d.MPa before the measures to 0.90m^3/d.MPa; From the perspective of fractured oil wells, the work diagram shows that the liquid supply capacity gradually becomes worse, and the bottom hole flowing pressure drops from 3.4Mpa to 0.3MPa.

3.2 Horizontal well infill combined with layer penetrating fracturing

The length of single horizontal section of three horizontal wells in l130 well block is 803m, and the encountered sandstone and oil-bearing sandstone are 697m and 611m respectively, with the penetration rate of 86.8% and 76.0% respectively; The average perforation section of a single well is 7.7, and the fracturing section is 6. The average fracturing fluid consumption of a single well is 1033m^3, and the sand addition is 117m^3. At the initial stage of production, the daily oil production of a single well is 5.0t.

The following understandings have been obtained by infilling horizontal wells and fracturing through layers:

First, the output of infill horizontal wells is 3.3 times that of peripheral vertical wells in the same period, which has achieved good production effect.

Second, from the perspective of water injection, effective displacement can be achieved. Fracture monitoring was carried out for 14 sections of 2 horizontal wells. The fracture length was 108~238m, and the displacement distance with the surrounding water injection wells was 53~145m, both within the effective displacement distance of 149m. After the water injection of the surrounding wells is resumed, the obvious effect characteristics are seen within 13 days. After the effect is received, water is seen along the fracture rapidly. 3 days after the water injection of the wells is stopped, the water content is restored to about 40%, and the water injection adjustment effect is obvious. The formation pressure is 12.78MPa, 3.73MPa higher than the surrounding vertical wells, maintaining a high level.

4. Conclusion

(1) The microscopic characteristics and percolation law of Gaotaizi reservoir are clarified, which lays a foundation for scheme design and fracture network optimization.

(2) The development and design idea of fracture pattern matching has been formed, the three technologies of vertical well fracture pattern fracturing, horizontal well location deployment and completion optimization, and zigzag horizontal well injection production system adjustment have been improved, and effective displacement has been established.

(3) Although infill horizontal well combined with through layer fracturing technology can establish effective displacement, it is affected by small injection production well spacing. On the one hand, the number of fracturing sections and fracture length are limited, affecting the initial production; On the other hand, the fractured water breakthrough phenomenon seriously affects the development effect.

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