

Development Strategy Research and Practice on Reservoir with Big Gas Cap and Narrow Oil Rim in Bohai Bay

YANG Qinghong^[a]; TONG Kaijun^{[a],*}; GE Lizheng^[a]; CHENG Dayong^[a]; NIE Lingling^[a]

^[a]Tianjin Branch of CNOOC Limited, Tianjin 300452, China.
* Corresponding author.

Received 7 May 2013; accepted 20 June 2013

Abstract

Reservoir of Es3-I in JZ25-1S oilfield in Bohai bay is a fault type characterizing in big gas cap, narrow oil rim and edge water. The main development problem in gas cap reservoir with vertical wells is coning from gas cap, which causes the oil wells ring gas channeling and seriously affects well productivity. Faced with a number of negative factors and aimed at low development degree of vertical wells, researchers present development from horizontal wells and apply a pilot test and numerical simulation to demonstrate the adaptability. Compared with vertical wells, some obvious advantages of horizontal wells can be demonstrated by deliverability, individual-well controlled reserves, and final development efficiency. The orientation, vertical location, trajectory and length of horizontal wells and production speed in the study areas were also optimally designed. In this optimal design, the length of horizontal segment should be 400 meters; while the vertical distance between the WOC should be a third, and conversely, two-third between the GOC. The horizontal well technology is proved to be helpful for the economic and high efficiency development in Es3-I oilfield. It is showed by the mining practice of horizontal well technology in seven horizontal wells located in the gas cap of JZ25-1S oilfield Es3-I reservoir that the application is good and the daily oil production of the single well is high, from 150 to 300 m³/d. It is proved that there is great potential of the horizontal well in development of the reservoirs with big gas cap and narrow oil rim, which can significantly increase the economic benefits of offshore oil fields and provides a reference for the development of other similar reservoirs.

Key words: Bohai bay; Big gas cap; Narrow oil rim; Horizontal well; Numerical simulation

Yang, Q. H., Tong, K. J., Ge, L. Z., Cheng, D. Y., & Nie, L. L. (2013). Development Strategy Research and Practice on Reservoir with Big Gas Cap and Narrow Oil Rim in Bohai Bay. *Advances in Petroleum Exploration and Development*, 5(2), 62-68. Available from: URL: <http://www.cscanada.net/index.php/aped/article/view/j.aped.1925543820130502.1492>
DOI: <http://dx.doi.org/10.3968/j.aped.1925543820130502.1492>

INTRODUCTION

Horizontal wells development technology can increase well production by expanding well drainage area, improving the development benefit of the oilfield. The horizontal well technique is applicable to the whole process of oil field development. In the early development stage of the oilfields, horizontal well has a high productivity, fast construction production, less investment and advantage characteristics of quick recovery; while in the middle-later period of the oilfields, straight wells development has poor potential benefits, the horizontal wells can be used as a cost-effective tapping of the ways and means for developing oil fields because of its larger oil drainage area, small producing pressure drop, restraining cut rising, improving well productivity and other advantages. Horizontal wells have been widely applied to thin reservoir, gas cap reservoir, edge and bottom water reservoirs, fractured reservoirs, heavy oil reservoirs, and low permeability reservoir. The development effect of the oilfield which used horizontal wells technology was well improved.

Narrow oil ring reservoir with big gas cap is one of the complex reservoirs, a certain proportion of the world has been found in various types of reservoir. Such reservoir has these particularity: The distribution relationship of oil, gas and water is complex; The strata has a certain inclination, and reservoir distribution recognize uncertainty; The exploitation of reservoir is difficult because cap gas channeling and edge water coning are easy to split the narrow oil ring. It is difficult to efficiently

develop narrow oil ring with big gas cap reservoir for improving oil recovery. The author based on the test mining information in JZ25-1S oilfield of Bohai bay, to study on the feasibility of horizontal wells to improve the narrow oil ring with big gas cap reservoir's oil recovery.

1. GEOLOGICAL CHARACTERISTIC

The Shahejie formation of JZ25-1S Oilfield is a sandstone reservoir with gas cap with the biggest investment in developing scale of Bohai Oilfield in recent years (as shown in Figure 1). A series of brachyanticline gas cap reservoirs controlled by structure were developed in the Es 2 of the early Tertiary Shahejie group in oilfield, with the most typical one of fault block (Es3-I). This block is a sandstone reservoir (gas cap index of 2.03, water multiples of 5 to 8 times, the width of the oil ring plane is less than 600m) with a typical characteristic of big gas cap, edge and bottom water and narrow oil ring. The reservoir mainly develops a braided river delta deposition and is mainly composed of fine sandstones with an average permeability of $325 \times 10^{-3} \mu\text{m}^2$ and an average porosity of 25%, which belongs to the medium-high porosity and permeability reservoirs. The ground oil density is 0.878 g/cm^3 , the formation oil viscosity is 0.71 MPa and the original gas-oil ratio is $70 \text{ m}^3/\text{m}^3$, which belongs to typical lightweight saturated crude. The directional wells are mainly developed in Overall development plan, but to ensure the efficient development of the oilfield, the feasibility of the development of narrow oil ring reservoir by drilling horizontal wells has been demonstrated from reservoir adaptability and capacity, and ultimately deployed a number of horizontal wells by the drilling way of paralleling with the fluid contacts, and formed a row well pattern and achieved a good development effect preliminary by optimizing the design.

2. FEASIBILITY ANALYSIS FOR DEVELOPMENT WITH HORIZONTAL WELL

2.1 Pilot Demonstration

Located in the north of the Liaodong Bay of Bohai Sea, JZ9-3 oil field is part of the Liaohu central bulge which overlaps the western Liaoning depression. The main oil zones of JZ9-3 oil field are the layers of E_3d_2 and E_3d_3 with the main type of structured layered reservoir including multi-GOW systems. One of them, the E_3d_2 -V layer is typical oil reservoir with bottom water and gas cap. In order to improve the development effect, we have designed an experiment area including a horizontal producing well and a directional producing well. Based on the performance of pilot production, turning the directional producing well to water injection well should be taken into account to replenish formation pressure.

Form the results of pilot production in experiment area since 2008, it is showed in Figure 2 that the situation of exploitation was well. The following characteristics are showed in the directional producing well: low initial production capacity ($60 \text{ m}^3/\text{d}$), high producing pressure (1.2 MPa), early water breakthrough (about 70 days), water cut rising fast, and high degree of gas channeling and so on. In contrast, the horizontal well has a higher initial production capacity ($125 \text{ m}^3/\text{d}$), a lower producing pressure (0.5 MPa), later water and gas breakthrough and so on. By the early of 2012, the cumulative oil production of horizontal well reached $13.7 \times 10^4 \text{ m}^3$ while the cumulative oil production of directed well is about $7.5 \times 10^4 \text{ m}^3$. Horizontal well is much better than directional well with the same geological characteristics. This successful development experience can be applied to other oil field.

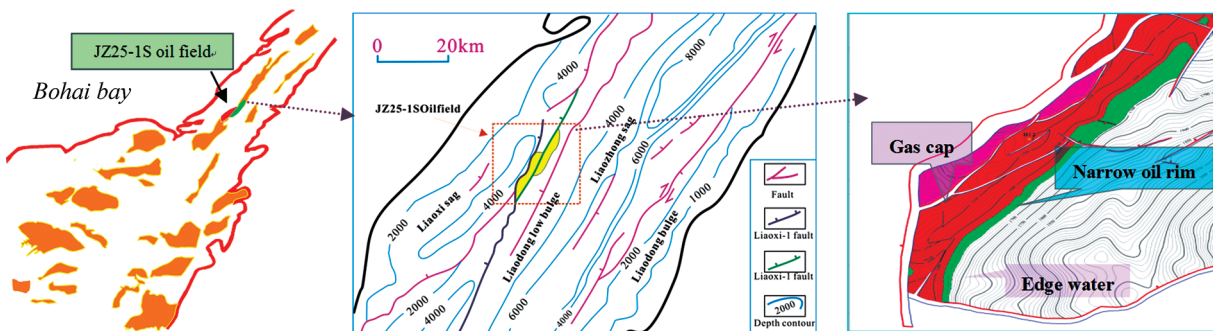


Figure 1
Location of JZ25-1S Oil Field in Bohai Bay, China

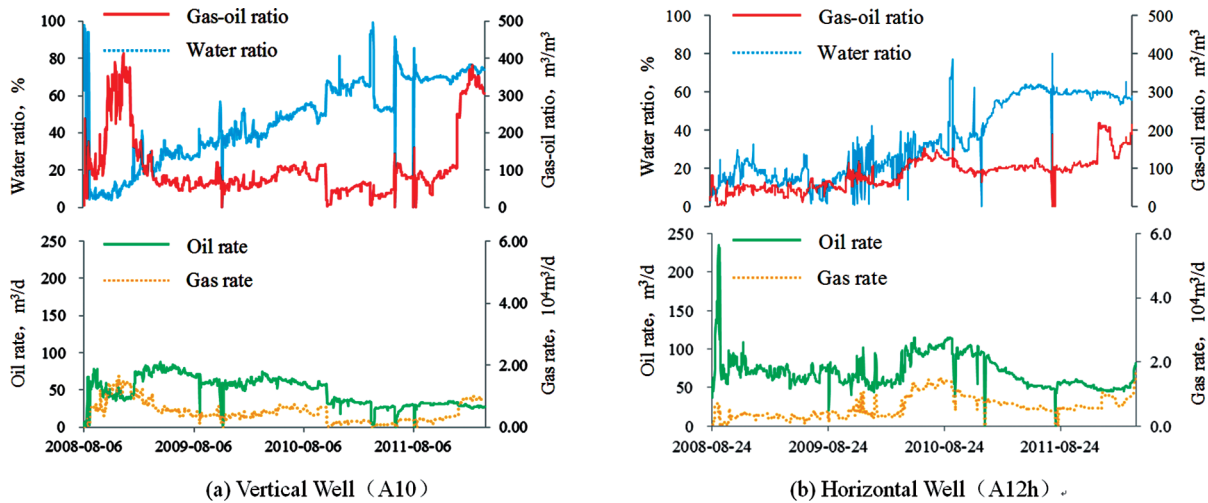


Figure 2
Development Effect Comparison for Different Wells in Same Reservoir

2.2 Numerical Simulation

According to geological and reservoir characteristics of the research area with a big Angle, Petrel software is used to describe the narrow oil rim distribution and all information are comprehensively applied including seismic data, well logging data, geological data, fluid analysis data and testing data. The typical numerical simulation model of reservoir with big gas cap and narrow oil rim in Bohai Bay is conducted. Then the development effect with different wells are simulated including five vertical well vs. three horizontal well based on the numerical model.

The simulation result shows that (as shown in Figure 3), there is a difference not only between gas channeling

and water coning time sooner or later but also a difference between gas and water breakthrough mode using different wells. When horizontal well is used to develop oil rim, top gas and bottom water mainly breakthrough by ridge shape and the time is much later; By comparison, when vertical well is used to develop oil rim, top gas and bottom water mainly breakthrough by coning shape and the time will be in ahead. Furthermore, it is showed in figure 4, the rate of rise of gas-oil ratio and water ratio is lower in horizontal well than vertical well and with in contrast with the rate of rise of oil rate and Cumulative oil rate. The simulation result shows there is a huge advantage to inhibit top gas channeling and bottom water coning by horizontal well.

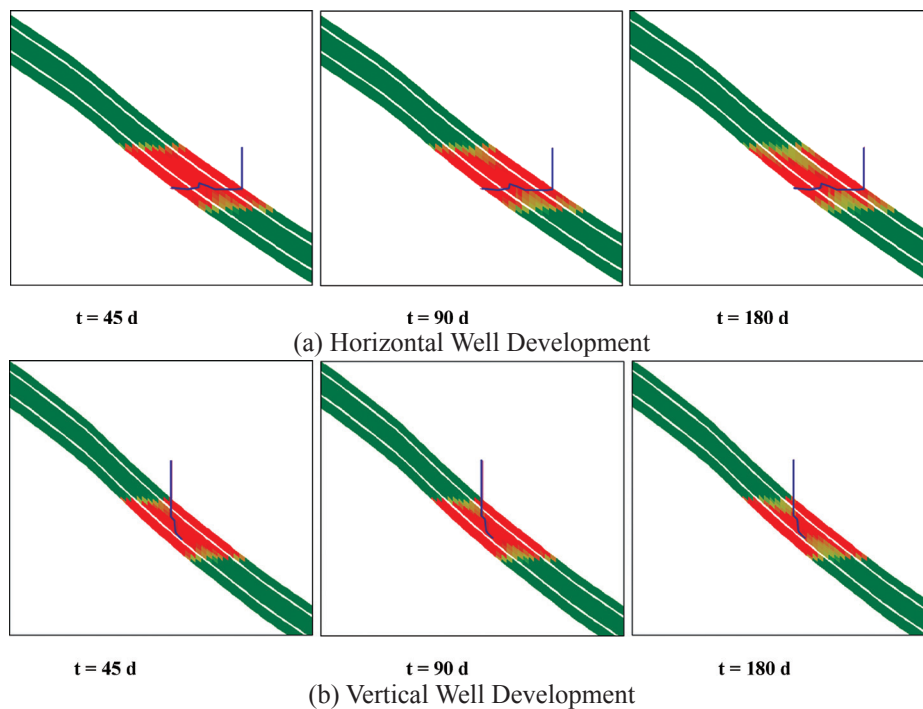


Figure 3
Dynamic Contrast of Gas and Water Coning Shape for Horizontal Well and Vertical Well in Different Time Steps

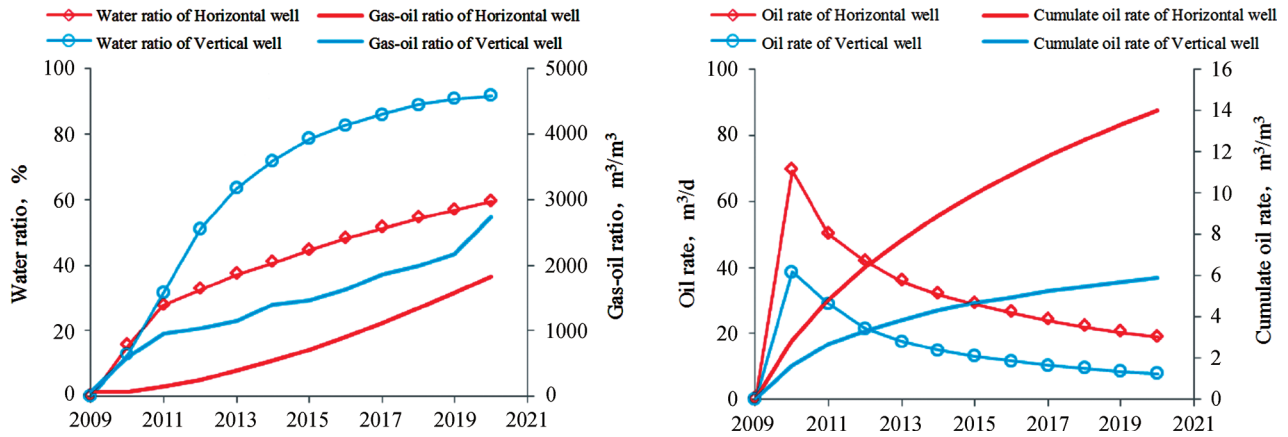


Figure 4
 Relationship of Gas-Oil Ratio and Water Ratio Changes with Time for Different Wells

3. EVALUATION OF HORIZONTAL WELL PRODUCTIVITY

To carry on DST fitting work based on numerical model, the fitting parameters including fluid rate, pressure, gas-oil ratio and water ratio should be fitted exactly. Then we can design the well location and perforation layer, also set simulation control parameters, for example, the maximum oil rate and skin factor. The simulation time step is not more than 1 month. According to the simulation results, we can analysis and evaluate the non-gas channeling period and its development effect under different well production conditions.

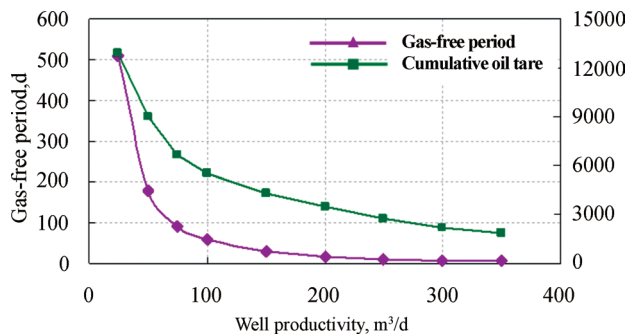


Figure 5
 Influence on Gas-Free Period with Change of Well Productivity

4. DEVELOPMENT STRATEGY RESEARCH FOR OIL RIM

4.1 Optimization for Development Mode of Oil Rim

Preventing oil and gas mutual channeling is key area to be considered in reservoir with big gas cap and narrow oil rim development. If gas invades into oil rim, the oil phase relative permeability will be declined and lead to cuts in production. On the contrary, when oil from oil rim invades into gas cap, it will lose a large section of reserves. Given the specificity of offshore oilfield, this paper only discusses development mode difference of oil rim. On the premise of using one gas well to develop gas cap,

The simulation result shows that (as shown in Figure 5), there will be a negative effect on reducing non-gas channeling period and Cumulative oil rate when the well early productivity is increased. But the influence specifically can be divided into two stages (as shown in Figure 6), in the first cases it is helpful for improving non-gas channeling period and Cumulative oil rate when the well early productivity is lower than 150 m³/d. In contrast, in the second cases there will be reducing non-gas channeling period and Cumulative oil rate and oil rim development effect when the well early productivity is more than 150 m³/d.

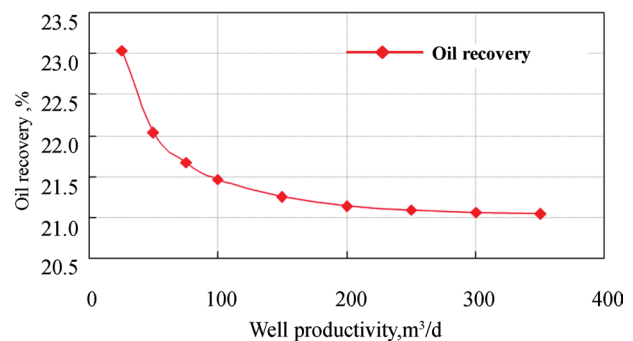


Figure 6
 Influence on Oil Recovery with Change of Well Productivity

several plans can be designed to simulate and evaluate the development effectiveness, such as: (1) Using seven horizontal oil wells under the natural depletion mode to develop oil rim; (2) Translating three horizontal oil wells into water injection wells under internal water flooding mode to develop oil rim; (3) Using seven horizontal oil wells and three vertical water injection wells under the edge water injection mode to develop oil rim; (4) Using seven horizontal oil wells and four vertical water injection wells distribution in gas-oil interface and three vertical water injection wells distribution in edge water under the barrier water injection mode to develop oil rim.

It can be seen in Figure 7, the cumulative oil rate of

nature depletion mode is 1335000 squares (Oil recovery is 22.3 percent); the cumulative oil rate of internal water flooding mode is 1164000 squares (Oil recovery is 19.4 percent); the cumulative oil rate of edge water injection mode is 1387000 squares (Oil recovery is 23.1 percent); the cumulative oil rate of barrier water injection mode is 1600000 squares (Oil recovery is 26.7 percent).

Based on the simulated results, we can know that barrier water injection mode will achieve the highest oil recovery among four plans and internal water injection is the worst plan comparatively. The oil recovery of nature depletion is not far from the traditional water injection mode. To sum up the difference among all plans as follows: Firstly, it will obtain better development

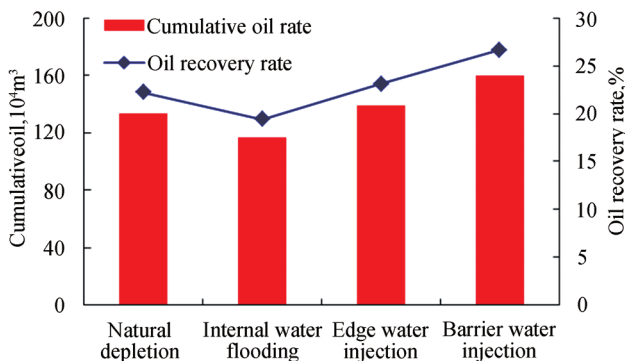


Figure 7
Development Effect Comparison for Different Mode

4.2 Development Design for Horizontal Well

4.2.1 Optimization for Vertical Location of Horizontal Well

Reducing the impacts of gas channeling and water coning, improving cumulative oil rate and responsible use of water and gas energy are key areas to be considered in horizontal well development. Another crucial factor in reservoir engineering is how to improve reserves producing degree and relieve unequal oil reservoir development. Because plane width of the oil rim is very narrow and there is an ecotone between top gas and bottom water but not pure oil zone, the vertical position of horizontal well will be impacted on the development effectiveness in oil rim. Several plans could be designed to simulate vertical position of horizontal well locating in oil-water interface from a third, a half to two-thirds and evaluate the development effectiveness. Figure 9 shows the optimization results of different vertical position of horizontal well to develop oil rim. The smaller physical distance of horizontal well to gas-oil interface, the sooner the gas channeling which will badly reduce the well productivity, and it will also reduce oil recovery rate. And in one case, the smaller physical distance of horizontal well to oil-water interface, the sooner the water coning which will be reducing period of water-free production, but it will mostly extend gas-free production.

effectiveness by making full use of gas cap and edge water energy and controlling of gas cap and oil rim producing rate reasonably for nature depletion mode; Secondly, Conventional water injection mode is difficult to form effective injection-production pattern, which will lead to water flood effect poorly and causing rich of inter-well remaining oil; One last point is that, the barrier water injection mode can effectively avoid oil and gas channeling each other, especially inhibit a large number of gas channeling into the oil ring, and reduce producing gas-oil ratio (as shown in Figure 8). Altogether, the effective development mode should be nature depletion for offshore oilfield to ensure the final development effectiveness and drilling cost.

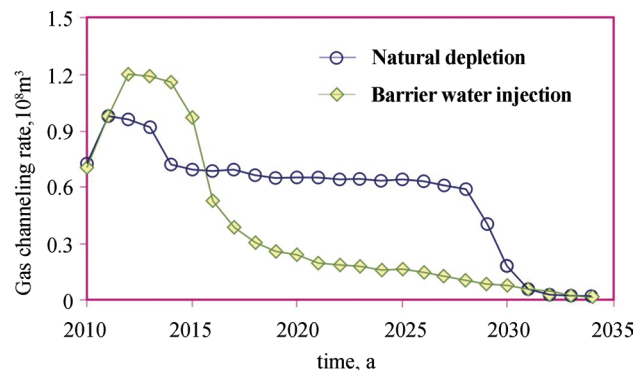


Figure 8
Dynamic Gas Channeling Rate Curve of Different Development Mode

For a specific reservoir with big gas cap and week wedge water, there will be mainly gas channeling in the process of development and the wedge water will inhibit gas channeling to some degree or another. Numerical simulation results show that the oil recovery rate of the vertical location of horizontal well to oil-water interface from a third, a half to two-thirds is 22.67, 21.95 and 20.81 percent, and therefore the final recommendation vertical location of horizontal well have to be designed on a third distance to oil-water interface.

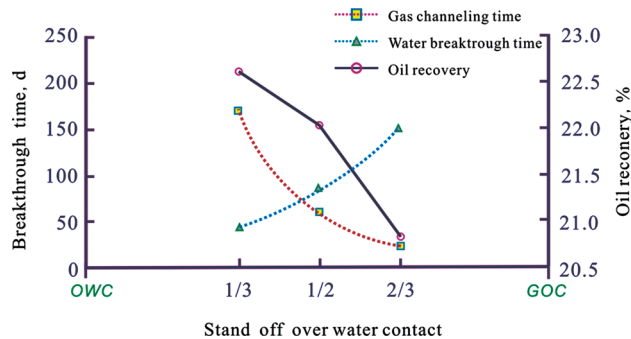


Figure 9
The Optimization of Horizontal Section Which Stands off the OWC in Big Gas Cap Reservoirs

4.2.2 Optimization for Length of Horizontal Well

In order to study different length of horizontal well development effect on oil rim, we apply the MSW module

(used in Eclipse software) which unlike traditional well would handle wellbore as a single mixing drum, it divides well bore into several intervals to simulate horizontal well by Eclipse software (as shown in Figure 9). Not only that, the MSW module could simulate also the change of fluid saturation along well bore be better and the effect of well bore friction on well productivity. When a good horizontal vertical position are selected, we can design several plans to simulate length of horizontal well which including 100 meter, 200 meter, 300 meter, 400 meter, 500 meter and 600

meter and also and evaluate the development effectiveness. Table 1 shows the optimization results of different length of horizontal well to develop oil rim. The longer the length of horizontal well, the development effectiveness at stable production period and final development stage is the better. But when the length of horizontal well is more than 400 m, the difference between all plans simulation results is very small. Length of horizontal well should be not more than 400 m to ensure the final development effectiveness and drilling cost.

Table 1
Optimization Table for Length of Horizontal Well

Length of horizontal well(m)	Well productivity		Pressure drawdown	Oil recovery(%)	
	Oil(m ³ /d)	Gas(10 ⁴ m ³ /d)	(psia)	Stable production period	25a
100	150	1.2	145.2	2.8	13.5
200	150	1.2	108.9	3.4	16.8
300	150	1.2	87.1	3.9	19.7
400	150	1.2	72.6	4.3	22.5
500	150	1.2	65.3	4.5	23.6
600	150	1.2	61.0	4.6	24.4

4.2.3 Reasonable Oil Recovery Rate for Horizontal Well

When a reasonable vertical position and length of horizontal well are selected, we can design several plans to simulate reasonable oil recovery rate of horizontal well which including 1.5, 3.5, 5.5 and 7.5 percent and evaluate the development effectiveness. In additional, the simulation conditions are fixed pressure drawdown, limiting the largest fluid rate and fixed the minimum flowing pressure and the maximum production period for 25a.

Table 2 shows the optimization results of different oil recovery rate of horizontal well to develop oil rim. The higher oil recovery rate, the better initial oil rate of oil rim, but the meantime, the bigger oil decline rate.

We can see that the most suitable oil recovery rate for oil rim development is 3.5 percent and the bigger than it, the oil recovery will decline. The main reason is that, with the continuous improvement of oil recovery rate, formation energy will be consumptive increasing and formation pressure level decline rapidly, all this will be resulting the more solution gas from oil rim and gas channeling from gas cap. Furthermore, when the oil recovery rate is 3.5 percent, the proportion of recovery percent with the production period of 5, 10 and 15 years is 62, 82 and 94 percent. We can achieve high efficient development for offshore oilfield and retrieve cost early from reasonable production.

Table 2
Optimization Table for Oil Recovery Rate of Horizontal Well

Oil recovery rate (%)	Pressure drawdown (psia)	Oil rate (m ³ /d)	Oil decline rate (%)	Cumulative oil rate (10 ⁴ m ³ /d)	Oil recovery (%)
1.5	29.04	257	20.0	127.1	20.3
3.5	72.60	600	26.0	140.9	22.5
5.5	113.26	943	32.0	136.5	21.8
7.5	159.72	1286	40.0	129.0	20.6

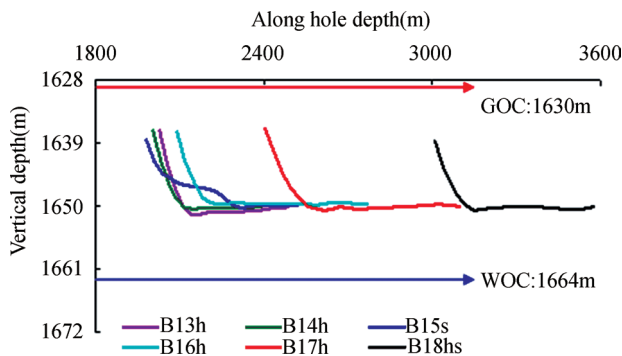


Figure 10
Comparison of Vertical Profile for Different Wells

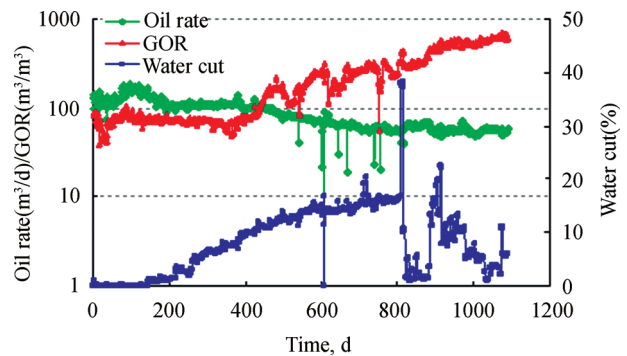


Figure 11
Production Performance Curve of Typical Well (B14h)

5. OILFIELD PRACTICE

Since Dec. 14, 2009, there have placed seven horizontal wells on oil rim and which have achieved good effect as follows(as shown in Figure 10): well productivity of 100-300 m³/d, and an average of 150 m³/d; gas-oil rate of 68-80 m³/m³, and an average of 74 m³/m³. By the end of Oct, 2012, the distribution of cumulative oil rate of individual-well is 70000-150000 squares. Cumulative oil rate have been 806000 squares by seven horizontal wells and the recovery percentage of OOIP is 12.9 percent. All this show that it has been achieved a truly high quality and efficient development for offshore reservoir with gas cap and edge water. Meanwhile the application of horizontal well B14h is analyzed and evaluated. Since 1000 days, cumulative oil rate of B14h is 94000 squares and cumulative gas rate is 12000000 squares. It can be see that the gas-free period of B14h has achieved 400 days and the water-free period is 230 days in Figure 11, and which fully demonstrate that horizontal well can change the flow field distribution and reduce the pressure drawdown and ultimately effectively restrain gas channeling and edge water coning to greatly improve the whole oilfield development effectiveness.

CONCLUSIONS

(1) After rigorous scientific technical demonstration and a comprehensive optimization for horizontal Wells parameters, it is possible to make use of horizontal well to develop reservoir with big gas cap and narrow oil ring and weak edge water. For a specific gas cap reservoir, there is a great advantage to inhibit gas & water breakthrough for horizontal well development than vertical well. In addition, there is an effective way to use horizontal well to improve producing rate and oil recovery.

(2) Evaluation of Horizontal well productivity results show that: appropriately reducing production proration is favorable to improve no gas channeling time and accumulation oil rate. Moreover, it can improve oil ring development effect for reservoir with big gas cap and narrow oil ring.

(3) Optimization of Horizontal well parameters results show that: it is helpful to inhibit gas breakthrough time and effectively relieve the offshore platform processing pressure when using horizontal segments with 400 meters to wear multiple formations and place it in the vertical 1/3 which distance OWC. Furthermore, it will achieve the highest oil recovery when taking in reasonable production speed based on natural energy fully. The actual production performance shows that using horizontal segments to parallel with OWC and GOC can indeed effectively control gas channeling and water coning and improve oil ring oil recovery.

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