Analysis of Production Characteristics of Reservoirs with Different Fluid Properties and Adjustment Strategies

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Abstract. In a certain overseas operation block of CNPC, the crude oil is gradually reduced from 19.4 API° to 8.8 API°. The development faces challenges such as poor effect of new wells and serious bottom water coning. In view of API gradual changing, this paper analyzes the fluid properties by means of geo-statistics, probes into the causes of API gradual change, summarizes the development characteristics of each fluid area according to the production dynamics, and puts forward differential adjustment strategies. The results show that: according to the API change, it can be divided into three regions: medium oil, heavy oil and extra heavy oil. The API gradual change is mainly the result of mixing normal crude oil and degraded crude oil. The production characteristics of each area are significantly different: the BOPD of individual well in the initial stage of medium oil is 752 bbl/d, which is 1.6 times and 73.0 times of that in heavy oil and extra heavy oil respectively; the initial decline of medium oil is 10%, and the later stage is gradually reduced to 86%; the initial water cut of the three regions are 27.7%, 35.1% and 94.3% respectively; the water cut rise of individual wells in the medium oil and heavy oil show "s" and "convex" rising rules respectively, while it is not obvious in the extra heavy oil. The recovery in the three regions is forecasted to be 28%, 25% and 14% respectively; differential adjustment strategies are proposed: Progressive exploration and water injection are the main strategies in the medium oil area; well pattern improvement and individual well workovers are the main strategies in the heavy oil area; individual well productivity problems will be solved in the extra heavy oil area through thermal production, electric screw pump and other processes. This paper puts forward the differential adjustment strategies for API gradual change, which can be used for reference for the same type of reservoir development.

Keywords: API · Initial production capacity · Decline rate · Water cut · Differential strategies

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1 Introduction

D oilfield is located in the Orent basin of South America [1], with an area of 3816 acres. Generally speaking, the oil field is a monoclinic structure with high northeast and low southwest, with low structural amplitude and formation dip angle of 1°–3.5°; M1 of Napo formation of Cretaceous system Sandstone is the main oil-bearing reservoir of the oilfield, and its lithology is mainly a set of quartz sandstone [2, 3], which is coarse in the lower part and fine in the upper part, showing a positive cycle, belonging to a typical transgressive sedimentary system; M1 sandstone reservoir has good physical properties, average porosity is 24.5%, average permeability is 2881md, and natural energy is sufficient. The fluid properties gradually deteriorated from southwest to northeast with API of 10°–24° and crude oil viscosity of 5.14–296.6cp. D Oilfield is a structural reservoir with high porosity, high permeability and low amplitude, which was found in 2014 and put into production in September 2015. As of March 31, 2020, 57 wells have been drilled, 53 wells are producing, with daily oil rate of 9688.6 bbl/d, comprehensive water cut of 80.3%, cumulative oil production of 14932.4 Mbbbl, oil recovery rate of geological reserves of 2.8%, and recovery degree of geological reserves of 10.9%. The oilfield is in the stage of high water cut and low oil recovery degree. Water injection development started in December 2019. The production curve is shown in Fig. 1.

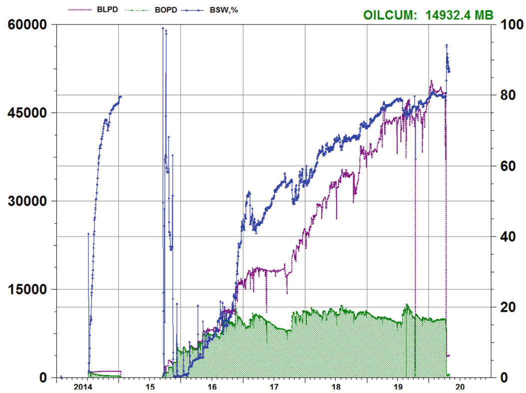

Fig. 1. Development and production performance of D oil field

After one year of development, the daily oil production of D oilfield has been maintained at about 10000 bbl/d since September 2016, when it reached 9287.3 bbl/d, reflecting a better development level. Generally, the oilfield shows the following development characteristics: 1. High production capacity in the initial stage of new wells; 2. High oil production speed; 3. Convex water cut, rapid water cut rise in the initial stage; 4. Sufficient natural energy, good reservoir pressure maintenance; 5. Water drive features natural water drive as the main and elastic drive as the auxiliary.

Generally speaking, the development of D oilfield has achieved good development effect and economic benefit. However, we should also see that at present, the oilfield also faces some challenges, mainly reflected in: 1. Due to the development strategy of high-speed production, the initial production capacity of new wells is high, but the decline of individual wells is fast, and the water cut rise is fast; 2. Due to the difference of crude oil fluid properties in the oilfield, the production characteristics of individual wells in different regions show great difference, production is unbalanced, and regional development effect is quite different; 3. Strong natural water drive results in better overall pressure level of the reservoir, but the local pressure in the region far away from the edge water drops rapidly.

In view of the above challenges, in order to achieve a better effect of oilfield development, it is necessary to refine the reservoir development unit for research, especially pay attention to the imbalance of oilfield development caused by the difference of fluid properties and the problem of great difference in development effect. Based on the difference of fluid properties, this paper divides the area by API differentiation, and makes dynamic analysis and evaluation respectively, so as to put forward differential development adjustment strategies, and provide experience for further improving the development effect of oilfield.

2 Differences in Fluid Properties

2.1 API Distribution of Crude Oil

According to the API test results of crude oil samples from individual wells, the API distribution of the oilfield is shown in Fig. 2; the PVT properties of fluid from individual wells are shown in Table 1.

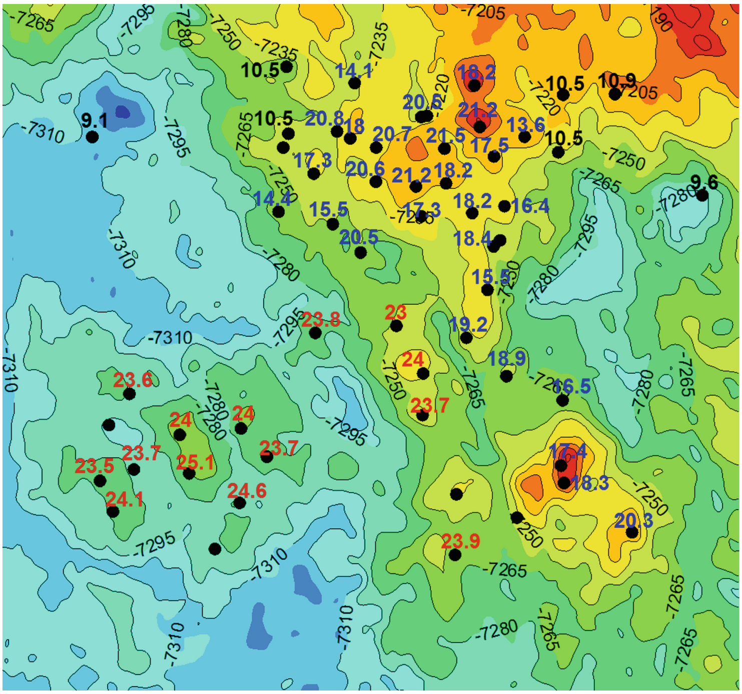

Fig. 2. API distribution of crude oil in D oil field

Table 1. Fluid PVT table of D oilfield

	D-02	D-04	D-03	D-06	D-11st	D-12
Pb (psi)	776	736	732	742	607	745
Oil gas ratio@Pb (scf/bbl)	145	156	159	189	107	207
Bo@Pb (vol/vol)	1.155	1.167	1.158	1.179	1.123	1.214
Density@Pb (g cm-3)	0.857	0.856	0.850	0.844	0.890	0.818
Viscosity@Pr (CP)	14.32	16.55	9.77	8.32	48.80	5.14
Viscosity@Pb (CP)	11.29	12.68	7.48	6.74	37.33	4.19
API (°)	19.4	18.4	20.9	22.2	16.2	24.6

According to Fig. 2 and Table 1, the API distribution of crude oil has obvious difference. According to the classification standard of heavy oil reservoir [4–6], the oilfield can be divided into three regions, i.e., medium oil in region I, heavy oil in region II and extra heavy oil in region III (see Fig. 3). Table 2 is the basic reservoir parameters of each region.

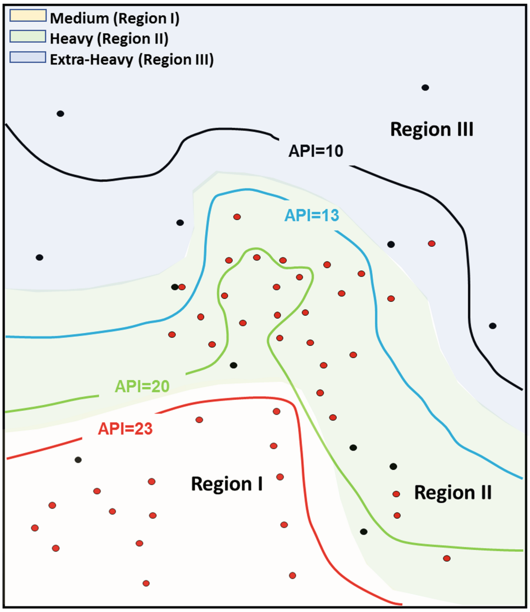

Fig. 3. Fluid division of D oil field

Table 2. Basic reservoir parameters in each region

Property	I region	II region	III region	D field
Reservoir mid depth (FT)	7307	7284	7289	7293
So, %	80	80	80	80
φ, %	24	24.4	25.2	24.5
Permeablity, mD	2710	2868	3066	2881.3
Saturation pressure (Psi)	745	714	493	651
Single phase compression factor (psi-1)	7.63E-06	6.502E-06	5.22E-06	6.451E-06
Oil-Gas ratio@Pb (scf/bbl)	207	145	58	137
Bo@Pb (vol/vol)	1.214	1.149	1.079	1.147
Density@Pb (g cm-3)	0.818	0.867	0.92	0.868
Viscosity@Pr (CP)	5.14	33.80	296.61	111.85
Viscosity@Pb (CP)	4.19	24.98	186.58	71.92
API (°)	24.6	18.55	10	17.7
Formation water viscosity@Pr (CP)	0.35209	0.35209	0.35209	0.35209
Oil-water viscosity ratio	14.6	96.0	842.4	317.7

2.2 Reasons for API Difference Distribution

The fluid properties of oilfield are so distributed because the structure of oilfield is high in northeast and low in southwest (see Fig. 4), and the source direction is from southwest to northeast. In the process of fluid migration from low part to high part, the light components in the fluid gradually volatilize, and the remaining heavy components remain, thus forming the current distribution trend of fluid API decreasing from southwest to northeast.

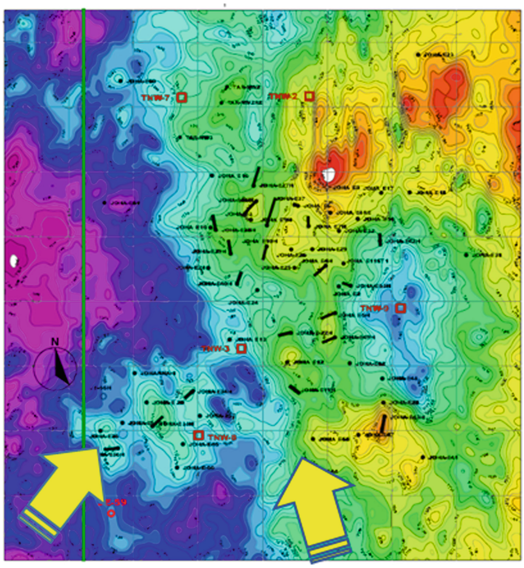

Fig. 4. Structural map of D oil field

3 Production Characteristics of Different Regions

3.1 Significant Difference in Initial Production Capacity of New Wells

Daily production and initial water cut of individual wells in different regions are shown in Fig. 5. It can be seen that due to the different fluid properties in different regions, there are obvious differences in the production capacity of new wells. The average initial oil production capacity of individual wells in region I is 1.6 times and 73.0 times of that in region II and region III respectively, as shown in Table 3.

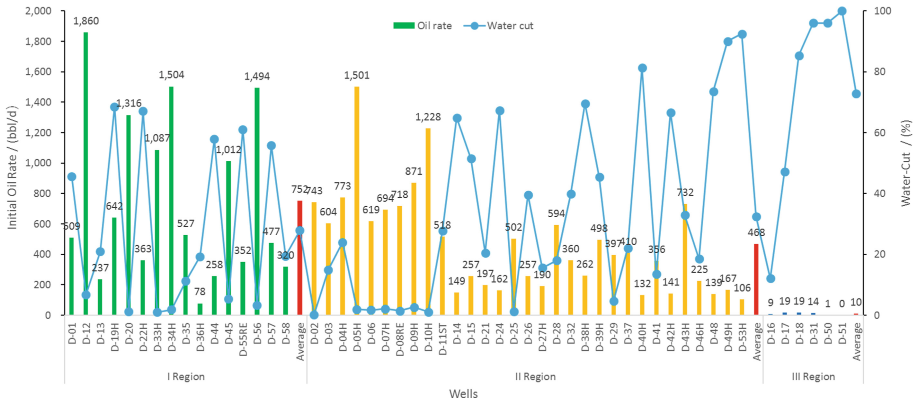

Fig. 5. Initial oil production rate and water cut of individual well in different regions

Table 3. Average initial production capacity of new wells in different regions

Region	BLPD	BOPD	Water cut, %
I	1039.7	752.1	27.9
II	720.5	467.8	32.5
III	180.8	10.3	72.8

It can be seen from Table 3 that the initial production capacity of new wells in region I is the best, with high daily liquid production rate, high daily oil production rate and low initial water cut. Region III, as it is a extra heavy oil region, has the worst new well productivity, low initial daily liquid production rate, low daily oil production rate and high initial water cut. While region II is a heavy oil region, the initial production capacity of new wells is between region I and region III.

3.2 Different Decline Rates of Old Wells

For region I, the oil is medium oil, and the continuous production cycle of wells reaches 41 months; the initial liquid production rate and oil production rate reach 1039.7 bbl/d and 752.1 bbl/d respectively, with water cut of 27.7%, but the initial decline rate is as high as 10%, and the later decline rate gradually reduces to 8.6% (see

Fig. 6). For region II, API is between 10°–22.3°, and crude oil fluidity is worse than that of region I. Initial liquid production rate and oil production rate are 720.5 bbl/d and 467.8 bbl/d, respectively, with water cut of 35.1%. Initial decline rate and later decline rate are 5.1% and 13.8% respectively (see Fig. 6). For region III, due to its extra heavy oil, API lower than 10°, insufficient formation liquid supply and poor crude oil fluidity, the initial daily oil output is 10.3 bbl/d, and water cut is 94.3% (see Fig. 6).

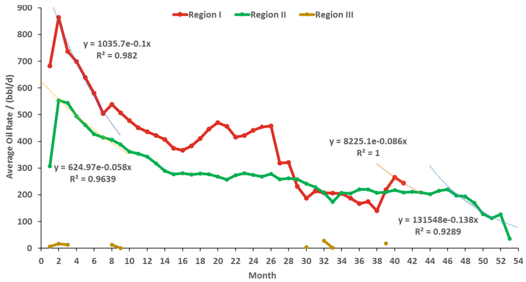

Fig. 6. Average decline curves of individual well in different region

3.3 Different Water Cut Rising Rules of Old Wells

For region I, the oil-water viscosity ratio is 14.6, which is relatively small, and the individual well shows the "s" type water cut rising rule (see Fig. 7); for region II, the oil-water viscosity ratio is 96, and the individual well water cut shows the "convex" type rising rule (see Fig. 7); for region III, due to the API is less than 10°, liquid supply capacity from formation is insufficient, and the water cut rising does not show the obvious rule (see Fig. 7). In the condition of same water cut rising rate, the water cut rising speed of region II is greater than that of region I (see Fig. 8).

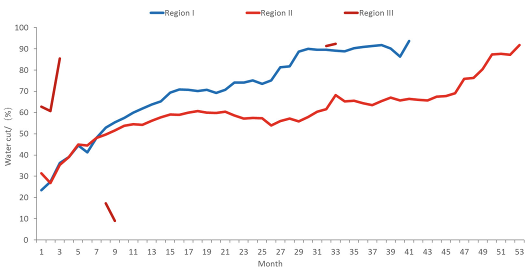

Fig. 7. Water cut rise curve of average individual well in each region

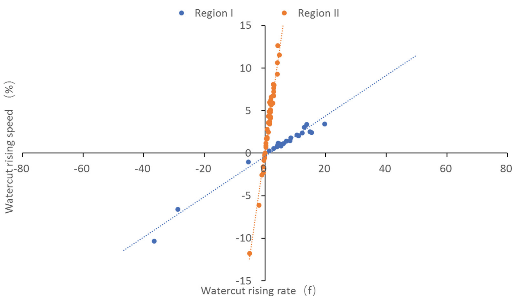

Fig. 8. The curve of water cut rising speed with water cut rising rate

3.4 Different Development Effects in Different Region

For region I, due to the sufficient edge and bottom water with the reservoir and the development strategy of oil production rolling exploration, the new wells are put into production later than region II, and gradually rolling improvement. The development well pattern in this region is gradually improved, the individual well productivity, the oil production rate and the recovery degree are high. According to the evaluation of water flooding [7, 8], the recovery rate of natural water drive in this region is about 28%. The development effect is even better than that of region II (see Fig. 9). For region II, the reserves are fully developed, the development well pattern is relatively perfect, the individual well productivity, the oil production rate and the recovery rate are high. The natural water drive recovery rate in this region is about 25%. Due to the low production capacity of individual well in region III, long-term continuous production is not possible. Therefore, production wells deployed is limited, resulting in a large number of reserves in region III unable to be developed. At present, it is still in the early stage of development, with low oil recovery rate and recovery degree.

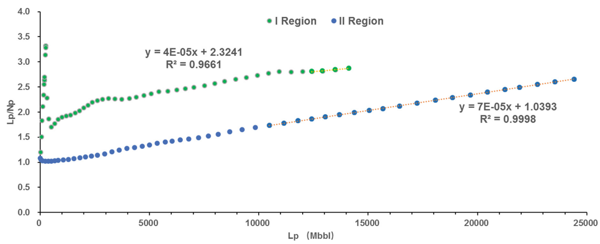

Fig. 9. Characteristic curve of water flooding in different API region

4 Adjustment Strategies

Based on the above analysis, different API regions of D oilfield have different fluid properties and show different production characteristics and different development effects in the production process [9, 10]. Based on this understanding, the development adjustment strategies for different API regions will be different, and the following three adjustment strategies are formulated:

(1) For the medium oil region, due to the low oil-water viscosity ratio, high displacement efficiency and good development effect, the future development adjustment strategy is to improve the production well pattern (new wells), gradually roll out the exploration (new wells), and adjust the development mode (water injection) at the right time.
(2) For heavy oil region, due to the large number of production wells, good production capacity, perfect well pattern deployment and good development effect, the future development strategy is to change the development mode (water injection development), locally improve well pattern (new well), and adjust individual well workovers. The development strategy after water flooding can consider polymer flooding to improve mobility ratio, but it needs to consider the economic efficiency of overseas oilfields and environmental protection requirements of resource countries.
(3) For the extra heavy oil region, due to the low recovery degree and bad development effect, the future development strategy is to make the overall development adjustment plan of extra heavy oil, especially to solve the individual well productivity problem through new engineering methods (thermal production, electric screw pump, etc.) [11, 12].

Under the guidance of the above adjustment strategies, the development and adjustment plans of the three regions are formulated and forecasted, and the key points and forecast results are as follows:

(1) Region I: 3 new wells with improving well pattern; 3 new wells with rolling edge exploration; carry out water injection in June 2020 with 2 water injection wells; 11 old wells (liquid increasing, re-completion and re-start), with 28% liquid increasing range (Fig. 10).
(2) Region II: 3 new wells with improving well pattern; start water injection development in December 2019, with 4 water injection wells; individual well workovers mainly include 19 wells with liquid increasing range of 25%, and 3 old wells are re-start (Fig. 10).
(3) Region III:The use of ESPCP can effectively solve the problem of carrying sand cooling in heavy oil reservoir, which can greatly improve the pump inspection cycle, reduce the number of operations and operating costs, and reduce the production cost.

After the above adjustment cases, it is estimated that the recovery rate will increase by 3.2% in the end of contract (see Fig. 11), which can achieve good development effect and economic benefit.

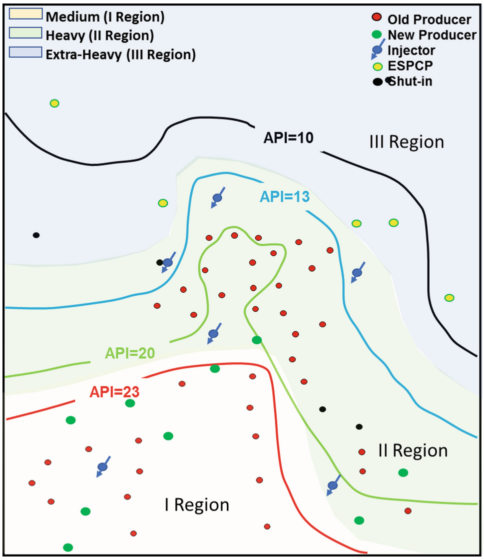

Fig. 10. Adjustment cases in different regions

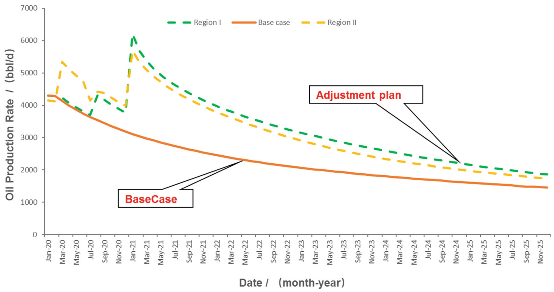

Fig. 11. Forecast of cases in different regions

5 Conclusions

This paper analyzes the development characteristics of different API region according to the production dynamics, and puts forward differential adjustment strategies. According to the research, conclusions are summarized as follows:

(1) According to API classification standard, D oilfield can be divided into three regions: medium oil region, heavy oil region and extra heavy oil region.

(2) The reason for the different distribution of API is that in the process of fluid migration from low part to high part, the light components in the fluid gradually volatilize and the remaining heavy components remain, thus forming the current distribution trend of fluid API decreasing from southwest to northeast.

(3) Due to the difference of fluid properties, there are obvious differences in production characteristics, recovery degree and development effect in each API region. The development effect of medium oil region is the best.
(4) Due to the different production characteristics and development effects, the development adjustment strategies are different. In the medium oil region, rolling edge exploration and water injection are the main strategies; in the heavy oil region, well pattern improvement and individual well workovers are the main strategies; in the extra heavy oil region, the individual well productivity problem is mainly solved by utilizing thermal production, electric screw pump and other processes.

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