A new method for production planning of offshore water flooding sandstone reservoirs

Jihui Luo, Mingguang Tang, Ruibin Lu, Shuangqi Liu, Qinghua Liu

Zhanjiang Branch of CNOOC Ltd., Zhanjiang, Guangdong 524057, China

Abstract

In order to solve the problem that there are big differences between the medium-to-long term output prediction of using the conventional method and practical results in the offshore water flooding sandstone reservoirs, this paper combined with the development characteristics of offshore oilfield, the division method of development stages is summarized, which is dominated by changes in oil production and contents in oil working, and supplemented by changes in recovery ratio. Meanwhile, the development indexes are chosen to describe yield in different development stages, such as decline rate, oil production rate, which can be used in production planning prediction. Combination the goal oil recovery which is calculated of the improved empirical formula of Exploration and Development Research Institute of Petro China, Established a new forecasting method for production. Field application results show that the method is simple and practicable, considering the differences of the development indexes in different stages, making the production planning results more close to the reality, ensuring the rationality of the recovery ratio, and improving the planning guidance.

Keywords

development stages; stages production index; recovery ratio; empirical formula; production planning.

1. Introduction

The changing regularity of the recovery ratio and output is an essential basis for oil field development planning, program design and adjustment[1,2].Now, there are many methods about the calculation of the oil recovery ratio and the output prediction, which mainly include decline curve analysis method, water flooding curve method, numerical simulation method[3],the mathematics model method[4,5] and the empirical formula method of the recovery ratio calculation[6,7].Two popular methods of the recovery ratio calculation and output long-term planning are production decline method and numerical simulation method, both of which are based on fitting the latest production data to predict, in the offshore oil field. The forecasting effect of production decline method is better in short term, but there would be great deviation in medium-to-long term yield prediction, as a result of ignoring the development characteristics of different stages. Numerical simulation method can consider the follow-up production measures, and the forecast precision is much high in medium-to-long term. However, this method is restricted by many factors. On the one hand, it is necessary that geological models is fine enough to reflect the reservoir characteristics and the underground structure, which is difficult to achieve for the few wells of offshore oilfield[8],not to mention untapped oil fields. On the other hand, the accuracy of historical fitting must be high, the adjustment of the parameters be reasonable, while the workload is heavy, and the subjective factors of the staff have a great effect on the results. These reasons lead to great deviation between long term production planning and actual production in the oilfield. Therefore, it is necessary to explore a production prediction method which can reflect the features of oilfield

development stages as well as simple and practical, in the premise of ensuring the oil recovery rate for a reasonable, which solves the problem of the large deviations.

Based on the developed marine sandstone oil field, the stages of oilfield development are divided by modifying the empirical formula of Research Institute of Petroleum Exploration and Development, PetroChina(RIPED), which calculate recovery ratio[9].By studying the development characteristics of each stage, the development indexes are summarized that describe the distribution of each production stage in marine sandstone oilfield. Then, combined with the calculation results of recovery ratio, the program of oil production planning is written, which was used to forecast the oilfield production in different development stages. The results show that the predictions is more accurate, the production planning more reasonable, the guidance more significant.

2. Description method of production distribution at stages

Taking the marine sandstone oilfield as an example, five typical reservoir is selected(Oilfield 1, Oilfield 2, Oilfield 3, Oilfield 4, Oilfield 9), the indexes are chosen to describe the characters of the production distribution at different stages after considering multiple evaluation indexes for dividing development stages.

2.1 Division of development stages

Rational division of oilfield development stages is helpful to systematic research the status of oilfield development and conclude the law of the periodical development. Mainly based on the oil recovery rate, combined the change of water content in oil reservoir, the development stages is divided[10~12], in which the oil production judges the effect of oil development, while the change of water content illustrate the main factors affecting oil production. Restricted by development conditions, just like high input and high risk, the development strategy is applied in the offshore oilfield, in which well is few but each well is high-output in the early stages of development. Generally, there is two times large well pattern adjustment, when the construction and geological understanding is clear, which results in that it is very difficult to copy the divided method and criteria of onshore oilfield development stages in the offshore oilfield.

Building on the sufficient analysis on the characteristics of oilfield development in the offshore oil field, referencing the approach of the stratigraphic division and correlation in geology, many indexes are taken into account, like the oilfield work content, production, water content rate, recovery degree. The oilfield work content and the change of production are the primary indexes, while the others is the secondary parameters. The development stages are divided through the horizontal comparison among the same types of reservoir.

Table 1 The development phase partition table of marine sandstone oilfields

Development stage	Production change	Relevant strategies	Water cut
Stage 1	Stable	Basic well pattern	Low water cut period (fw≤9.4%)
Stage 2	Rapidly falling	First well infilling	Medium water cut period (9.4%<fw≤57.9%)
Stage 3	Slow falling	Second well infilling+conventional measures	High water cut period (57.9%<fw≤82.3%)
Stage 4	Low yield	Conventional measures	Ultra-high water cut period (>91.1%)

The development of marine sandstone reservoirs can be divided into four stages (Tab. 1, Fig. 1).The first stage is the low water cut stage, in which the oil well production is high, and the measure of increasing production is few, also named the stage of efficient development and trial production;The second stage is the medium water cut stage, in which it is mainly to improve the well network

deployment and the production declines fast, known as the well pattern adjustment stage;The third stage is the high water cut stage, the development of the medium-to-late stage, in which the conventional measures to adjust occupy a larger proportion, and the decline of production becomes slow;The fourth stage is the extra high water cut stage, in which oil wells maintain a low level of production, also namely the late stage of development.

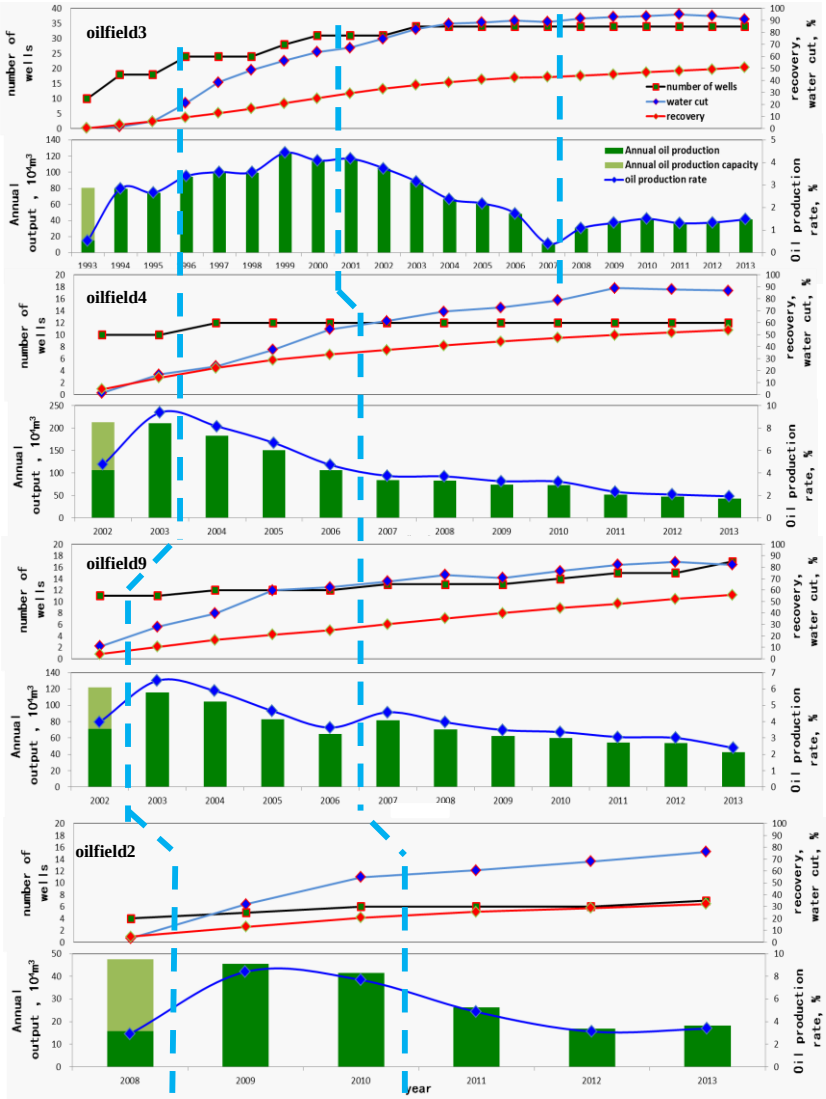


Fig.1 Division results of marine sandstone oilfields development stages

2.2 Distribution law of main development indexes at different stages

By using the method mentioned above, the development characteristics of the different stages can be fully reflected in the whole development history of an oilfield.At different development stages, the development indexes show a good regularity.

(1) Stage characteristics of decline rate

Marine sandstone oilfield is always integrated development. Stable production time is short, and the decline rate is fast with obvious periodic characteristics (Tab. 2), which presents low-high-low characteristics as a whole.

Table 2 the production decline law for different development stages of marine sandstone oilfields

Oilfield	Low water cut period	Midium water cut period	High water cut period	Ultra-high water cut period
Oilfield 3	0.04	0	0.18	0.08
Oilfield 9	0.01	0.28	0.13	
Oilfield 4	0	0.17	0.07	
Oilfield 1	0	0	0.08	
Oilfield 2	0	0.27	0.18	

(2) Stage characteristics of oil production rate

Oil production rate shows a downward trend with the increasing of water content at different water cut stage(Fig. 2). The average oil production rate decreases from the initial 5% to 1.4% of the extra high water cut stage.

(3) Stage characteristics of water cut rising rate

In general, water cut rising rate is rising fast at the first stage, and the later stage is gradually decreasing in marine sandstone oilfield (Fig. 3). The average water content in the low water cut stage was 2.7%, 2.1% in the medium water cut stage, 1.4% in the high water cut stage, 1.3% in the extra high water cut stage.

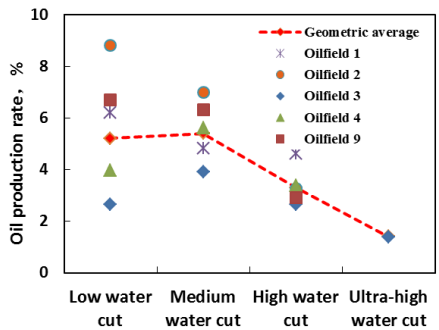


Fig.2 Changes of oil production rate for different development stages of marine sandstone oilfields

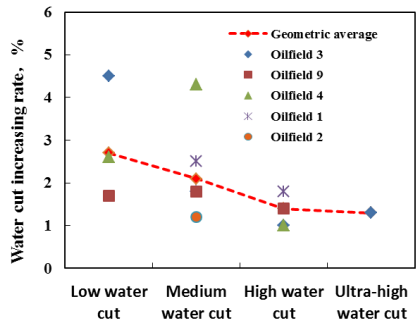


Fig.3 The variation of water cut for different development stages of marine sandstone oilfields

2.3 Determination of development indexes at each stage

Based on the rational division of the development stages, the development indexes of various stages are obtained by the method of statistical analysis in 8 water flooding sandstone reservoirs (Table 3).The production planning methods all take the geometric average of the characteristic indexes as the basic parameters to calculate the output data in each development stage of the same oil reservoir.

Table3 Summary table of main production index for different development stages

Reservoir type	Oilfield	Stage 1						Stage 2						Stage 3						Stage 4					
		water cut %	water cut increasing rate %	annual decreasing rate a^{-1}	annual production rate %	recovery percent %	well controlled reserves 10^4m^3	water cut %	water cut increasing rate %	annual decreasing rate a^{-1}	annual production rate %	recovery percent %	well controlled reserves 10^4m^3	water cut %	water cut increasing rate %	annual decreasing rate a^{-1}	annual production rate %	recovery percent %	well controlled reserves 10^4m^3	water cut %	water cut increasing rate %	annual decreasing rate a^{-1}	annual production rate %	recovery percent %	well controlled reserves 10^4m^3
Natural water drive	Oilfield 9	17.0	1.70	0.01	6.70	14.1	118.3	54.7	1.80	0.28	6.3	33.7	107.1	86.9	1.40	0.13	2.90	53.9	90.0	—	—	—	—	—	—
	Oilfield 4	11.0	2.60	0.00	3.98	4.0	162.0	59.7	4.30	0.17	5.6	21.0	127.3	82.1	1.00	0.07	3.38	49.6	68.5	—	—	—	—	—	—
	Oilfield 1	19.3	—	0.00	6.20	3.5	52.2	56.8	2.50	0.00	4.8	13.1	45.9	78.3	1.80	0.08	4.61	27.0	33.8	—	—	—	—	—	—
	Oilfield 2	3.4	—	0.00	8.80	4.7	135.2	54.8	1.20	0.27	7.0	25.6	90.1	76.1	2.40	0.18	3.25	32.1	50.5	—	—	—	—	—	—
	Oilfield 3	6.0	4.50	0.04	2.64	9.4	89.7	63.8	1.80	-0.06	3.9	21.1	61.8	88.8	1.00	0.18	2.64	43.0	44.1	91.1	1.3	0.08	1.39	51	44.1
	Geometric average	9.4	2.71	0.02	5.21	6.1	103.9	57.9	2.11	0.26	5.4	21.9	81.0	82.3	1.43	0.12	3.29	39.8	54.1	91.1	1.3	0.08	1.39	51	44.1
Water flooding	Oilfield 6	25.1	1.40	0.03	5.40	12.4	101.9	69.5	6.30	0.36	2.9	21.1	78.4	54.9	3.20	0.09	1.20	31.8	67.9	—	—	—	—	—	—
	Oilfield 5	0.3	0.07	0.04	2.10	2.1	142.0	49.8	3.80	0.06	1.9	19.3	52.5	—	—	—	—	—	—	—	—	—	—	—	—
	Oilfield 7	10.9	1.41	0.16	5.33	8.4	52.0	32.8	0.57	-0.023	4.8	27.9	29.0	—	—	—	—	—	—	—	—	—	—	—	—
	Geometric average	4.1	0.52	0.06	3.92	6.0	91.0	48.4	4.89	0.15	2.3	20.2	64.2	—	—	—	—	—	—	—	—	—	—	—	—

3. New method of production planning and its application

3.1 New method of production planning

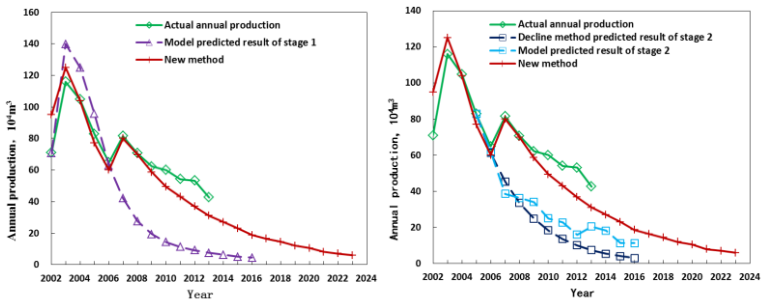
Production planning in the new method, firstly, though improving the target recovery ratio formula, combined with the statistics of development well controlled reserves at the various stages, the degree of recovery is calculated in all stages of development. And then according to the development characteristics, like decline rate and water cut rising rate in each development stage, production planning is worked out in the middle-to-long term.The basic process is as follows.Firstly, calculate the well density of the different stages by using the oil-bearing area and the well controlled reserves at each stage statistically, and figure out the degree of recovery and stage production capacity according to the selection formula of mobility value in reservoirs, combined with the core oil displacement efficiency.Secondly, calculate the oil production and water production every month in stage I by development indexes, like decline rate and water cut rising rate in each development stage. And judge production conditions. When the cumulative production time is less than the calculated production time and cumulative oil production is less than the calculation of recoverable yield, calculate the oil production, water production of next month.If the cumulative production time of this stage is greater than the calculation of production time, the excess part is calculated in the next phase.Thirdly,the result that using the target recovery rate minus the first three stages of the recovery degree by the formula, is the amount of recoverable oil production in fourth stages. In this way, the yield distribution of this stage can be determined.

3.2 Practical application

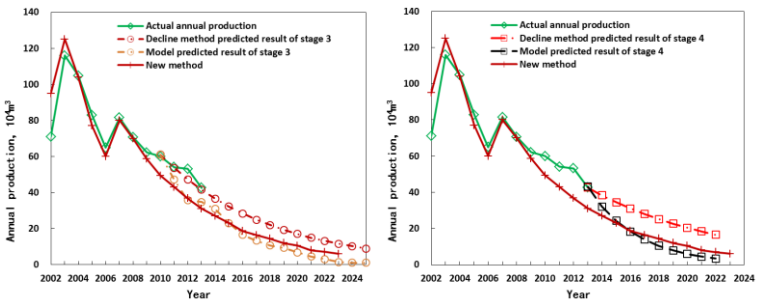
X production oilfield belongs to marine sandstone reservoir in the offshore Oilfield, and now the oilfield has entered the high water cut stage.In order to confirm the practicability and effectiveness of the new method, it is applied in the production prediction of the oilfield, and the results are compared with the conventional method.

As shown on the Fig. 3 and Tab. 4, in the medium and low water cut stage (the first and the second stage), the difference between the predicting results of conventional method and the actual production data is large, and the predicted recovery ratio is only about 35%.Due to the production decline is the fastest in the second stage of the marine sandstone reservoir, the predicted result of production decline method is the lowest.In the high and the extra high water cut stage (the third and the fourth stages), the production decline is slow, resulting in that the predicted result of decreasing method is optimistic slightly, while the prediction results of production planning method is between numerical simulation method and production decline method, in which the difference between the prediction recovery ratio with the result of numerical simulation method is only 0.7%.In addition, the planning yield distribution is almost consistent with the characteristics of the marine sandstone oil field, and the law of production decline represents slow-fast-slow characteristics as a whole.

The new method, production planning method, is simple and practical, which can not only effectively avoid the influence of production trend at different development stages, but also take increase production measures into account, like the effect of conventional work and well adjustment, which reduces the risk of occurring large deviation in long-term production planning.



a b



c d

Fig.3 Predicted curves of production planning method vs. convention method

Table 4 The result table of production planning method vs. conventional method

Development stage	Stage1			Stage2			Stage3			Stage4	
	numerical simulation	output programming	decreasing method	numerical simulation	output programming	decreasing method	numerical simulation	output programming	decreasing method	numerical simulation	output programming
Predicted cumulative oil production 10^4m^3	640.7	997.4	601.5	670.4	997.4	1096.2	952.7	997.4	1098.4	984.8	997.4
Predicted oil recovery %	35.95	55.97	33.75	37.62	55.97	61.52	53.46	55.97	61.64	55.26	55.97

4. Conclusion

1.Based on the development characteristics in offshore oilfield, taking the changes in oil production and the content of the work as the main indexes to divide, oilfield water cut as the auxiliary indexes in the divided method, the development indexes have been extracted in describing the yield at different development stages.

2.Put forward a new production planning prediction method in which oil recovery ratio is calculated by the improved formula and the yield is predicted in different stages with different development indexes. The practical application shows that this method is simple and accurate, which has good application value for undeveloped and developed oilfield production planning.

Acknowledgment:

Financial support from Research on the dynamic evaluation technology and development potential of water flooded layer in the western South China Sea(YXKY-2014-ZJ-01).

References

[1] Liu Bin, Guo Xiuwen. Economic recovery of oilfield and its calculation[J]. China Offshore Oil and Gas. 2001,15(3).200-203.

[2] Guo Youlian. The importance of the application of decreasing method to calculate oil recovery[J]. Inner Mongolia Petrochemical Industry.2010.68- 69.

[3] National Energy Administration. SY/T 5367- 2010 The estimated methods of oil recoverable reserves[S].Beijing:China Standard Press, 2010.

[4] Zhao Yushuang. A Method of Production Prediction of the Planning Arrangement for Chang Yuan Oilfield of Daqing [J]. Science Technology and Engineering, 2011,11(25): 6154-6158.

[5] Chen Yuanqian, Yuan Zixue. A NEW MODEL FOR PREDICTING PRODUCTION AND RESERVES OF OIL AND GAS FIELDS[J]. ACTA PETROLEI SINICA, 1997,18(2):84-88.

[6] Wang Shuhua, Xu Jinghua. Evaluation and study of recovery rate prediction method for newly-proved reserves[J].Petroleum Geology & Experiment,2012,34(5):490-494.

[7] Shang Mingzhong and Sun Huanquan.Methods of determining oil recovery in different development stages[J].Petroleum Geology and Recovery Efficiency,1995,2(2):46-52.
[8] Lei Xiao,Zhang Qiaoliang, Luo Jihui, etal. Fine characterization technique of remaining oil after water flooding for complex fault block reservoirs in southeast Weizhou oilfield group and its application [J]. China Offshore Oil and Gas, 2015, 27(4):80-85.
[9] Luo Jihui, Lu Ruibin, Jiang Lili, etal. An Improved Method for Determining Reasonable Well Controlled Reserves and Recovery Factor [J]. Science Technology and Engineering. 2015,06. 15(17).49-52
[10] Zhao Mingyuan. A DISCUSSION ON THE DIVISION OF THE STAGES IN THE SANDSTONE OIL FIELD DEVELOPMENT [J]. Petroleum Exploration and Development, 1986 (2):51-57.
[11] Gao Lifu. Development stage division theory of La-Sa-Xing oilfields [J]. Oil-Gas field Surface Engineering, 2008, 27(2):31-32.
[12] Li Qiong. The division and prediction of the development stages in Xi Nanzhuang oil filed [J]. Journal of Mineralogy and Petrology, 1998.06,18 (2):67-69.