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Characterization of Productivity Construction Patterns and Medium-to-Long-Term Production Prediction of Adjustment Wells in Offshore Oilfields

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Abstract

In recent years, Bohai Oilfield has continuously intensified its adjustment and potential tapping efforts. Adjustment wells have become a key measure for increasing production in offshore oilfields, contributing significantly to output. However, with the persistent rise in water cut and the increasingly complex distribution of remaining oil, the difficulty of predicting the medium-to-long-term production of adjustment wells has increased substantially, severely constraining the accuracy of development planning. To address this issue, this study systematically analyzes the productivity construction patterns of different potential-tapping types in Bohai Oilfield based on dynamic development data and incorporates a key quantitative indicator of productivity construction effectiveness—the Productivity Coefficient (PC). An innovative multi-dimensional evaluation system for the effectiveness of productivity construction in offshore oilfields has been developed, and a methodology for predicting the medium-to-long-term production of adjustment wells has been established. Application of this method in the Bohai BZ Oilfield indicates that the future average annual production scale of adjustment wells is approximately 7×10^4 tons to 10×10^4 tons, with prediction results aligning well with actual development dynamics. This research provides a theoretical foundation and decision-making support for medium-to-long-term production planning in Bohai Oilfield.

Keywords

Offshore Oilfield, Adjustment Wells, Potential-Tapping Types, Productivity Coefficient, Production Prediction

1. Introduction

To fully achieve the construction goal of "Oil and Gas Resource Supply Guarantee Center," Bohai Oilfield has continuously deepened geological and reservoir research. Adjustment and potential tapping have become crucial measures for enhancing production in offshore oilfields, with remarkable contributions. However, as the comprehensive water cut rises and the distribution of remaining oil becomes more complex, potential-tapping types have evolved from primarily internal infilling in the early stages to a mixed scenario including edge potential tapping, complex structural areas, and others. This shift has significantly increased the difficulty of predicting the medium-to-long-term production of adjustment wells, making it essential to clarify the productivity construction patterns under different potential-tapping types (Fan et al., 2003; Luo et al., 2015).

Significant progress has been made in productivity prediction for onshore oilfields. For instance, Bie et al. (2004) combined mathematical statistics and reservoir engineering methods to systematically analyze the productivity fulfillment rate, development indicator trends, and economic effectiveness of PetroChina's projects. Li and Xu (2004) applied a systematic index evaluation model to establish a method for optimizing productivity construction projects, enhancing the comprehensiveness and accuracy of evaluations. Gong et al. (2009) used the productivity coefficient as a core indicator to summarize the productivity construction characteristics of 417 new productivity blocks in Shengli Oilfield since the 10th Five-Year Plan. However, these methods do not fully account for the "low well count with high production" development mode characteristic of offshore oilfields. Lu et al. (2016) developed a relationship model between recoverable reserves and the time interval of production for adjustment wells in the western South China Sea oilfields based on statistical analysis, which can be used to predict recoverable reserves for adjustment wells not yet implemented. Nevertheless, it fails to distinguish the differential impact of various potential-tapping types on production patterns. Lin et al. (2022) developed a productivity prediction model for horizontal wells in offshore fields, incorporating various secondary completion sand control methods. This was achieved by modifying the skin factor to account for formation damage during drilling, completion, and workover operations, considering factors such as formation parameters and completion techniques. However, the model primarily focuses on the influences related to drilling and completion. Yang and Xiang (2023) established an empirical formula chart for the productivity of the LSG formation in the Beibu Gulf area.

This was done by analyzing productivity data from the region using a new productivity factor method and developing a multiple regression VBA program. Their work, however, does not address medium-to-long-term production prediction.

In summary, existing studies have yet to establish a quantitative indicator system for the effectiveness of productivity construction tailored to the characteristics of offshore oilfields. There is also a lack of methods for predicting medium-to-long-term production of adjustment wells that incorporate the heterogeneity of potential-tapping types. Therefore, it is imperative to develop an evaluation index system for the effectiveness of productivity construction in offshore oilfields and establish a production prediction method that integrates potential-tapping types, thereby providing theoretical support and a decision-making basis for the scientific formulation of medium-to-long-term production targets in the Bohai Oilfield.

2. Literature Review and Study Framework

2.1. Analysis of Potential-Tapping Types for Adjustment Wells in the Bohai Oilfield

As Bohai Oilfield enters the high water-cut development stage, the complexity of remaining oil distribution continues to increase, leading to significant changes in potential-tapping modes. Initially, development focused on internal infilling to enhance recovery through well spacing optimization. Currently, it has evolved into a multi-type synergistic potential-tapping approach, including internal refined infilling controlled by reservoir architecture, edge reserve mobilization, rolling development of new zones and blocks, and complex reservoir types (such as lithologic sand bodies, thin layers, and oil column push-down). This diversity poses considerable challenges to predicting the production of adjustment wells.

Statistics from field dynamic data show that as water cut rises, the structure of potential-tapping types undergoes significant changes: the proportion of internal infilling wells has been decreasing at an average annual rate of 1.9%, while the proportions of edge potential tapping, new zone/block, and complex potential tapping wells have continued to rise. Notably, the combined proportion of adjustment wells for edge and new zone/block potential tapping has exceeded 27% (Figure 1). The diversification of potential-tapping modes considerably increases the uncertainty of medium-to-long-term production prediction.

For systematic analysis, potential-tapping types for adjustment wells are categorized into three classes: internal potential tapping, edge/new zone/block potential tapping, and complex potential tapping (including lithologic sand body mobilization, thin layer mobilization, and oil column push-down). Subsequent studies on productivity construction patterns are conducted based on this classification. Taking Year 8 as an example, the well counts were 151 for internal potential tapping, 45 for edge/new zone/block potential tapping, and 3 for complex potential tapping.

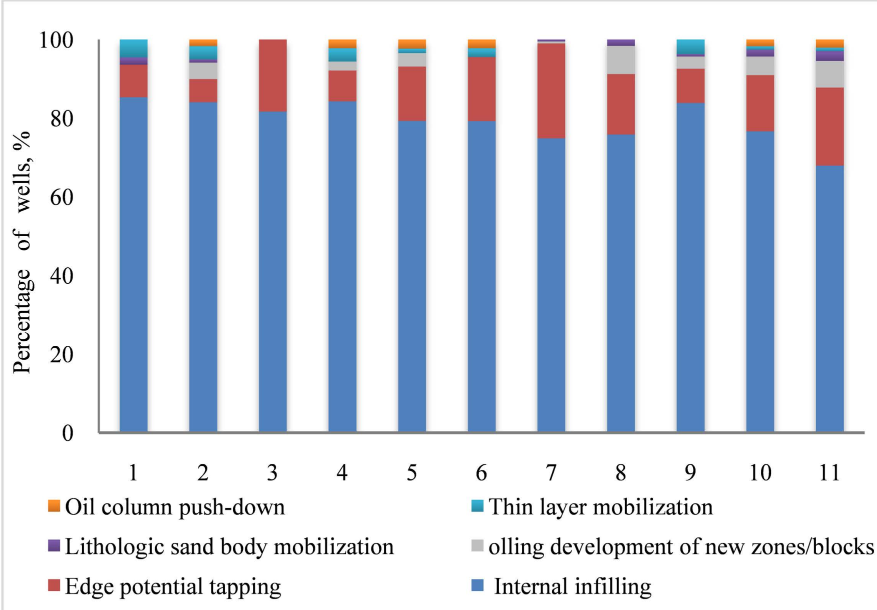

Figure 1. Proportion of adjustment wells by potential-tapping type in the Bohai Oilfield over the years.

2.2. Study on Productivity Construction Indicators of Adjustment Wells with Different Potential-Tapping Types in Bohai Oilfield

2.2.1. First-Year Single-Well Daily Oil Production of Adjustment Wells by Potential-Tapping Type

Large-scale field data statistics reveal significant differences in the first-year single-well daily oil production of adjustment wells across different potential-tapping types as water cut increases. Overall, edge/new zone/block potential tapping has the highest daily production, averaging 77 m^3/d, while complex potential tapping has the lowest, averaging 64 m^3/d. Internal infilling potential tapping averages 67 m^3/d. Internally, the daily oil production of internal infilling and edge/new zone/block potential tapping shows a declining trend over time, indicating increasingly dispersed remaining oil and greater challenges in potential tapping. In contrast, the daily production of complex potential tapping wells remains relatively stable, with significant annual fluctuations, suggesting the presence of remaining oil enrichment areas in non-main sand bodies, which are key targets for future potential tapping.

2.2.2. Productivity Coefficient of Adjustment Wells by Potential-Tapping Type

Based on reservoir engineering life-cycle theory, the production dynamics of adjustment wells are divided into three characteristic phases:

1) First-year production construction period (0 - 12 months, productivity construction phase);

2) Second-year peak production period (13 - 24 months, high production phase);

3) Third-year decline period (25 - 36 months, natural decay phase).

The "Productivity Coefficient" (PC) is introduced as the ratio of the actual annual oil production to the newly constructed production capacity of the block, to quantitatively evaluate the effectiveness of productivity construction for different potential-tapping types. Here, the "newly constructed production capacity" refers to the annual oil production level that all producing wells should achieve after the full commissioning of the oilfield. This is determined under a specific extraction method, assuming wells produce according to their designed operating strategy and considering the achievable production time efficiency (production time rate).

The productivity coefficient for a new well over the years is calculated as:

$$x = \left\{ \frac{b_1}{a}, \frac{b_2}{a}, \frac{b_3}{a}, \cdots, \frac{b_n}{a} \right\} \tag{1}$$

$$b = \left\{ b_1, b_2, b_2, \cdots, b_n \right\} \tag{2}$$

where x is the productivity coefficient; $b_1, b_2, b_2, \cdots, b_n$ are the annual oil production (in 10^4 tons) from the first to the n-th year after the new adjustment well is put into production; and a is the newly constructed production capacity (in 10^4 tons) of the new adjustment well. This value is typically taken as the annual oil production of the new wells in their first full calendar year of operation or in the second calendar year after commissioning.

The productivity coefficient, generally ranging from 0 to 1, reflects the production increase and stabilization status of new adjustment wells. Analyzing the changes in the productivity coefficient across different time periods and potential-tapping types allows for a reasonable evaluation of productivity construction effectiveness and provides guidance for medium- to long-term production prediction of adjustment wells.

Based on tracking data from over 1600 adjustment wells in the Bohai Oilfield (covering 61 development units), the productivity coefficients for the first three years of different potential-tapping types are calculated using Equations (1) and (2) (see **Table 1** for internal infilling as an example). The first-year productivity coefficient for the three potential-tapping types ranges from 0.48 to 0.53, averaging around 0.5, and is primarily influenced by production time rates, including differences in drilling and completion cycles, discrete production timing, and varying cleanup periods of new wells, all of which significantly impact the first-year production contribution of adjustment wells. The second-year productivity coefficient varies by potential-tapping type, ranging from 0.70 to 0.79. Generally, the productivity construction phase concludes by the second year, with adjustment wells reaching peak production and the highest productivity coefficient. By the third year, production enters a decline phase, with productivity coefficients of 0.59 for internal infilling and 0.54 for both edge/new zone/block and complex potential tapping.

2.2.3. Peak Production Decline Rate of Adjustment Wells by Potential-Tapping Type

The peak production decline rate is calculated based on the productivity coefficients of the second and third years for different potential-tapping types (**Figure 2**). The decline rates in the third year are similar for internal infilling and edge/new zone/block potential tapping, at 21.2% and 22.5%, respectively. Complex potential tapping, affected by the deteriorating quality of reserves and targets, has the highest peak production decline rate at 32.2%. For internal infilling, the peak production decline rate varies across different batches over the past decade, generally ranging between 18.3% and 26.5%.

Table 1. Productivity coefficients of adjustment wells for internal infilling potential tapping in the Bohai Oilfield over the years.

Year	Internal Infilling		
	1	2	3
1	0.49	0.60	0.49
2	0.55	0.73	0.54
3	0.52	0.75	0.61
4	0.58	0.76	0.61
5	0.47	0.76	0.57
6	0.53	0.76	0.61
7	0.51	0.84	0.63
8	0.47	0.75	-
Average	0.51	0.75	0.59

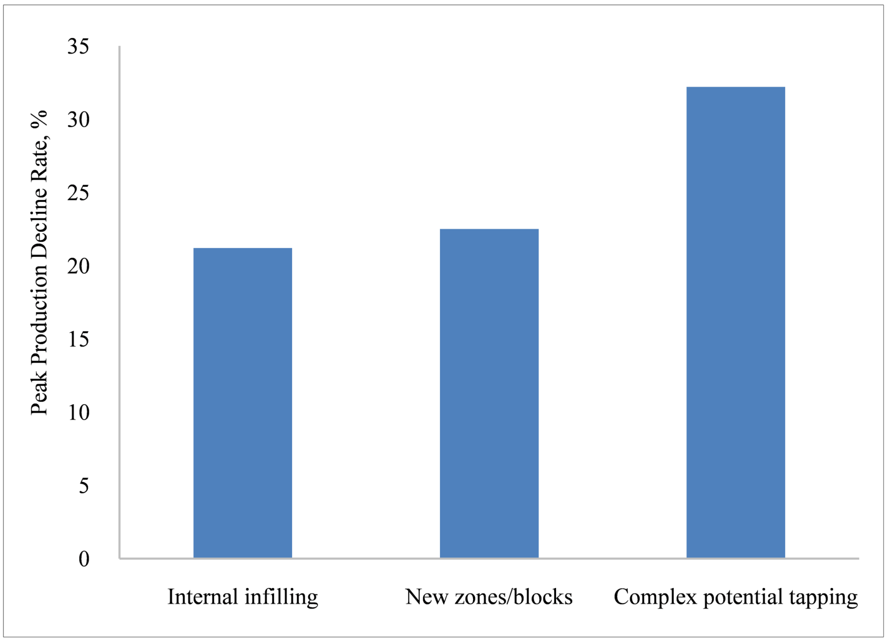

Figure 2. Peak production decline rates of adjustment wells by potential-tapping type in the Bohai Oilfield.

The main factors influencing the productivity coefficient are generally reserve quality and development supporting technologies (Qin, 1989; Dong et al., 2001;

Qiu, 2002; Gao et al., 2003; Jiang et al., 2003; Xie & Yi, 2006). When geological and reservoir conditions are favorable and supporting technologies are mature, the productivity coefficient during the peak phase can reach 0.93 or even 1.00, with a relatively lower post-peak decline rate. For complex potential-tapping types such as lithologic sand body mobilization, thin layer mobilization, and oil column push-down, the average productivity coefficient during the peak phase is generally high due to relatively concentrated remaining oil. However, factors such as immature supporting technologies, strong reservoir heterogeneity, poor connectivity, or insufficient energy support lead to a significant decline in the third year.

2.3. Medium-to-Long-Term Production Prediction and Productivity Construction Effectiveness Evaluation System for Adjustment Wells in Offshore Oilfields

In the prediction process, the future well count trend is first inferred based on the proportion of various potential-tapping well types. Key indicators such as first-year single-well daily oil production, productivity coefficient, and peak decline rate (**Table 2**) are then integrated to comprehensively predict the medium-to-long-term production profile of adjustment wells.

Table 2. Production prediction indicators for adjustment wells by potential-tapping type in the Bohai Oilfield.

Potential-Tapping Types	Well Count Proportion, %	Annual Change Rate of Future Well Count, %	First-Year Single-Well Daily Oil Production, m^3	First-Year PC	Second-Year PC	Peak Production Decline Rate, %
Internal infilling	76	−1.9	67	0.51	0.75	21.2
New zones/blocks	19	0	77	0.48	0.7	22.5
Complex potential tapping	5	1.9	64	0.53	0.79	32.2

Based on the analysis of different potential-tapping patterns, key evaluation indicators for adjustment wells are selected, and quantitative standards at the Bohai level are established. A multi-dimensional evaluation system for the effectiveness of productivity construction in the Bohai Oilfield is developed to provide technical support for planning adjustment well programs in producing oilfields (**Table 3**).

3. Application

In actual planning, the productivity coefficient is used to evaluate the rationality of indicators for various potential-tapping types and to predict the scale of adjustment well construction. By benchmarking planning indicators against historical indicators of producing oilfields, production risks and potential can be assessed. Integrating numerical simulation and reservoir engineering methods enables comprehensive production prediction and profile optimization for oilfields, achieving refined medium-to-long-term production prediction for adjustment wells in Bohai Oilfield. Application in the Bohai BZ Oilfield shows that the future average annual production scale of adjustment wells is 7×10^4 - 10×10^4 tons, with prediction results consistent with actual development dynamics, demonstrating the reliability of the method.

Table 3. Evaluation system for productivity construction effectiveness in the Bohai Oilfield.

Key Performance Indicator	Potential-Tapping Types	Value
Productivity Coefficient (PC), f	Internal infilling	0.51; 0.75
	New zones/blocks	0.48; 0.70
	Complex potential tapping	0.53; 0.79
Peak Production Decline Rate, %	Internal infilling	21.2
	New zones/blocks	22.5
	Complex potential tapping	32.2

4. Conclusion

This study systematically reveals the productivity construction patterns of adjustment wells in the Bohai Oilfield and establishes a production prediction methodology tailored to the characteristics of offshore oilfields. The main conclusions are as follows:

1) The structure of potential-tapping types displays dynamic evolution characteristics: the proportion of edge and new zone/block potential tapping increases yearly, while the proportion of internal infilling wells decreases at an average annual rate of 1.9%. Analyzing productivity patterns based on potential-tapping types is essential for scientific prediction.

2) The productivity coefficient effectively quantifies productivity construction effectiveness: Based on the production phase characteristics of adjustment wells (production construction, high and stable production, decline), the productivity coefficient indicator is innovatively constructed. Statistical analysis of Bohai Oilfield shows that the average first-year productivity coefficient is 0.50, increasing to 0.75 in the second year, with an average annual decline rate of about 22.0% after the peak phase. The productivity coefficient provides a unified quantitative benchmark for evaluating the effectiveness of different potential-tapping types.

3) A multi-dimensional evaluation system supports refined prediction: An innovative multi-dimensional evaluation system for productivity construction effectiveness is established, incorporating key indicators such as well count proportion, single-well daily oil production, productivity coefficient, and peak decline rate. Application in the BZ Oilfield indicates an average annual production scale of adjustment wells of 7×10^4 - 10×10^4 tons, with results highly consistent with historical production dynamics, verifying the reliability of the method.

The productivity evaluation and production prediction method developed in this study deepens the understanding of productivity patterns in adjustment wells under complex development conditions. It provides important theoretical support and a practical basis for the scientific planning of medium-to-long-term production targets and the optimization of development decision-making in the Bohai Oilfield and similar offshore oilfields.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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