

Multi-Factor Grey Correlation Analysis of Horizontal Well Development Effect in Chunguang Oilfield

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Abstract: Chunguang oilfield is a lithologic trap reservoir with edge water drive, whose horizontal well development effect is influenced by static factors and dynamic factors. In the process of production, the influences of static factors including reservoir physical properties and dynamic factors including working system, liquid production velocity on horizontal well development effects are different, and it is difficult to find main factor influencing horizontal well development effect with conventional single-factor analysis method. Combined with static and dynamic data of Chunguang oilfield, using multi-factor grey correlation analysis method, quantitative relationships between horizontal well development effect and different factors are systematically analyzed. Main factors influencing horizontal well development effect and dynamic influence laws between different factors and horizontal well development effect are clarified. Problems existed in the development process are known and it can provide the direction for future development and adjustment of Chunguang oilfield.

Keywords: Horizontal well, Development effect, Influence factors, Grey correlation, Permeability.

1. INTRODUCTION

Chunguang oilfield is a lithologic trap reservoir with edge water, whose oil area is small and edge water is active. Horizontal wells are used in many development units [1]. In the development process, water cut of horizontal well increases quickly, oil production rate decreases, sand production of formation is serious, and the development effect is bad. At present, main factors influencing horizontal well development effect is not clear.

Many scholars at home and abroad researched the factors influencing horizontal well development effect. The results indicated that there are many factors influencing horizontal well development effect including static factors and dynamic factors [2-8]. In the process of horizontal well development effect evaluation, it is found that single influence factors are insulated and it is difficult to find main factor influencing horizontal well development effect with conventional single-factor analysis method. Therefore, it is needed to use proper method to analyze and correlate horizontal well development effect with multi-factors, find main factor and dynamic influence regulars of horizontal well development effect, make clear development adjustment direction, and establish foundation for improving horizontal well development effect.

2. SINGLE-FACTOR ANALYSIS OF DEVELOPMENT EFFECT AND THE LIMITATIONS

Based on Joshi's research achievement, deliverability formula of horizontal well can be expressed as [9]:

$$Q_0 = \frac{2\pi k_{ro} k_h h \Delta p}{\mu_0 B_0 \left[\ln \frac{a + \sqrt{a^2 - (L/2)^2}}{L/2} + \frac{\beta h}{L} \ln \left(\frac{\beta h}{2\pi r_w} + s \right) \right]} \quad (1)$$

$$\text{where, } \beta = \sqrt{k_h/k_v}, R_{eh} = \sqrt{A/\pi}$$

$$a = \frac{L}{2} \sqrt{0.5 + \sqrt{0.25 + (2R_{eh}/L)^4}}$$

Q_0 —oil production rate of horizontal well, m^3/s ; R_{eh} —oil drainage radius of horizontal well, m ; r_w —well radius of horizontal well, m ; L —length of horizontal well, m ; A —oil drainage area of horizontal well, m^2 ; K_h , K_v —horizontal and vertical permeability, m^2 ; K_{ro} —oil relative permeability, dimensionless; h —thickness of oil layer, m ; a —semi-major axis of horizontal well drainage area, m ; μ_0 —formation oil viscosity, $Pa \cdot s$; B_0 —formation oil volume factor, m^3/m^3 ; S —skin factor of horizontal well; ΔP —production pressure drop, Pa .

From Eq. (1), we can know that oil production rate of horizontal well is related to oil layer's absolute permeability, relative permeability, thickness, production pressure drop, oil physical property, length of horizontal well section, drainage radius of horizontal well, heterogeneous coefficient and skin factor. These factors can be divided into natural geologic factors and development factors [10]. According to characteristics of the factors, they can also be divided into static and dynamic factors.

For a specific horizontal well, static parameters such as reservoir permeability, reservoir thickness, physical property of crude oil, length of horizontal well section, drainage radi-

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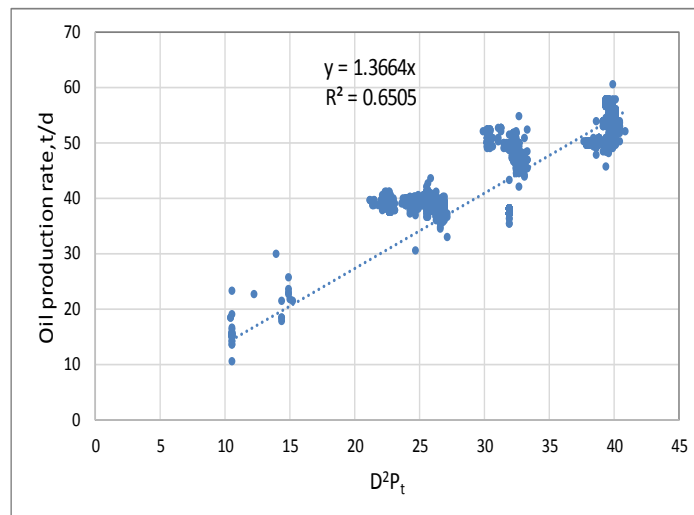


Fig. (1). Relationship between oil production rate and choke & tubing pressure of well P2-P31 ($Q_o = 1.3364D^2 \cdot P_t$).

us of horizontal well, heterogeneous coefficient, skin factor *et al.* remain unchanged. Main parameters influencing oil production rate are producing pressure drop and oil phase relative permeability. Producing pressure drop are mainly affected by working system of individual well (or liquid producing rate of individual well) and liquid production rate of unit (or block). Oil phase relative permeability are mainly affected by water saturation. According to the theory of Buckley-Leverett, water saturation is related to water-cut. Therefore, oil production rate is related to liquid producing rate of individual well, liquid production rate of unit and water-cut and so on.

Usually, supposing that some natural flowing wells without water production has approximately same oil/gas ratio, and relative density of ground crude oil changes rarely, and surface tubing pressure (upstream pressure of choke) is twice as large as wellhead back pressure (downstream pressure of choke), there is an approximate relation between oil well production rate and oil pressure & diameter of choke.

$$Q_o = CD^2 \cdot P_t \quad (2)$$

Where, Q_o is oil production rate, t/d; D is hole diameter of choke, mm; P_t is tubing head pressure, MPa; C is choke factor.

In the production processes of Chunguang Oilfield, pressure maintenance degree is high, bottom hole flowing pressure of producing well is higher than saturation pressure, and production gas/oil ratio is the same as primary gas/oil ratio. According to oil production rate Q_o of horizontal well before producing water, choke diameter D and tubing pressure P_t , regression analysis result indicated that the relationship between Q_o and D^2P_t is linear. According to Fig. (1), oil production rate increases along with the increase of choke diameter and tubing pressure. Through adjusting working system, the oil production rate can be adjusted, but daily oil production rate should be reasonable to prevent edge water advancing quickly.

Edge water advancing of a single horizontal well is not only influenced by individual well liquid producing rate (or

working system) but also affected by liquid production velocity in the whole unit (or block). Where, liquid producing rate is daily produced liquid mass or volume and the liquid production velocity is the ratio of annual liquid volume to OOIP of unit. For example, the daily oil production rate of a single well P2-P89 is 25~30t/d. Besides, the liquid production velocity in the unit is more than 10% over a long period of time, as shown in Fig. (2). Oil production rate of single well and liquid production velocity of the unit can both lead to quick advancing of edge water. It is very difficult to distinguish whether oil production rate of single well or liquid production velocity in the unit is the main factor influencing advancing of edge water.

Initial oil production rate of horizontal well in Chunguang Oilfield is affected by static factors such as reservoir kh value, the length of horizontal well section L and so on. But in the process of long-term production, static factors and dynamic factors (such as working system and liquid production velocity) have different influences on development effect of horizontal wells. Only analyzing from single factor, it is difficult to identify whether large liquid production rate of single well or high liquid production velocity of unit causes advancing of edge water and decrease of oil production rate for horizontal well. Therefore, it is necessary to use multi-factor correlation method to analyze development effect of horizontal wells.

3. MULTI-FACTOR GREY CORRELATION ANALYSIS

3.1. Grey Correlation Analysis Method

The influencing factors for development effect of horizontal wells in Chunguang Oilfield are complex and numerous. It is significant for system analysis to analyze the correlation property among factors, to quantify the correlation degree, to sequence the correlation degree and to judge the dynamic correlation property. Grey correlation analysis is a statistic analysis technology, which is mainly used to analyze close degree between parent factors and sub-factors in the

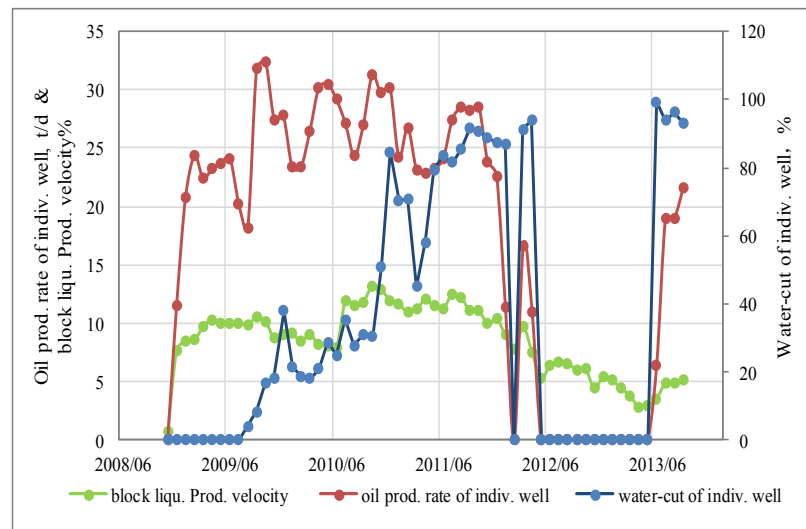


Fig. (2). Production index of well P2-P89 and liquid production velocity of unit.

system, and identify the major factors and secondary factors that lead to the development and changes of the system. Grey correlation analysis is a method that can quantify and compare system dynamic developing situation [11-13].

Suppose that reference array is $X_0 = \{x_0(k), k = 1, 2, \dots, n\}$, and the compared array (factor array) is $X_i = \{x_i(k), k = 1, 2, \dots, n\}, i = 1, 2, \dots, m$ so the grey correlation degree $\gamma(X_0, X_i)$ between X_0 and X_i can be defined as the formula below:

$$\gamma(X_0, X_i) = \frac{1}{n} \sum_{k=1}^n \gamma[x_0(k), x_i(k)] \quad (3)$$

where,

$$\gamma[x_0(k), x_i(k)] = \frac{\min_i \min_k |x_0(k) - x_i(k)| + \rho \max_i \max_k |x_0(k) - x_i(k)|}{|x_0(k) - x_i(k)| + \rho \max_i \max_k |x_0(k) - x_i(k)|} \quad (4)$$

In the formula, ρ is resolution coefficient, and $\rho \in [0, 1]$, usually $\rho = 0.5$. The correlation array assembly can be obtained by arranging m array correlation degrees $\gamma(X_0, X_i)$ from high to low. This can be used to identify the relative degree between array X_i and X_0 .

3.2. Results of Grey Correlation Analysis

The changes of oil production rate reflect the influences of many factors such as reservoir physical property, heterogeneity, development well network, liquid production velocity, working system and so on. Now take oil production rate in different time as reference array and take influence factors as compared array (factor array), at the same time adopt multi-factor grey correlation methods to analyze the main factors influencing oil production rate or development effect.

Take Well P2-P89 as an example. The reference arrays and factor arrays of each year is shown in Table 1. The annual oil production rate of a single well represents the changes of development effect. The annual liquid production rate represents the influences of working system of the well itself on oil production rate. Water-cut of single well represents the influences of well's water content change on oil

production rate. Liquid production velocity of the unit represents the influences of producing environment in whole unit on oil production rate of single well. Thickness of oil layer "h" (or other static information) represents the influence of static factors on oil production rate.

Calculate the correlation coefficient in each year according to grey correlation analysis (Table 2). The results of grey correlation analysis indicate:

$$\gamma(X_0, X_1) > \gamma(X_0, X_2) > \gamma(X_0, X_4) > \gamma(X_0, X_3)$$

Make a comprehensive rank for various influential factors of each year: single well working system (or liquid production rate) > liquid production velocity of unit > static geologic factor > water-cut. Grey correlation factor in each year can also be seen from Table 2 and Fig. (3). For example, rank of influential factors in 2010 is that: static factors > liquid production velocity of unit > single well working system (or liquid production rate) > water-cut.

According to the analysis results in Table 2, it is known that due to the large liquid production rate of well P2-P89, the edge water advances quickly and oil production rate drops. Liquid production velocity has also some influences on well P2-P89, but the influential degree is lower than liquid production rate of the well itself. For well P2-P89, the liquid production rate (or working system) is the main factor to influence the development effect. Therefore, it is supposed to maintain reasonable working system, to prevent edge water advancing quickly, to prevent water-cut increasing quickly, and improve the development effect of horizontal wells.

CONCLUSION

1. On the condition that static parameters do not change, oil production rate is mainly influenced by dynamic factors such as liquid production rate of single well (or working system), liquid production velocity of unit, water-cut and so on. Through multi-factor grey correlation analysis and grey relative degree calculation, the influential degree of various factors can be analyzed quantitatively, and the main factors

Table 1. Grey correlation analysis data of well P2-P89 (take oil production rate of single well as the reference array).

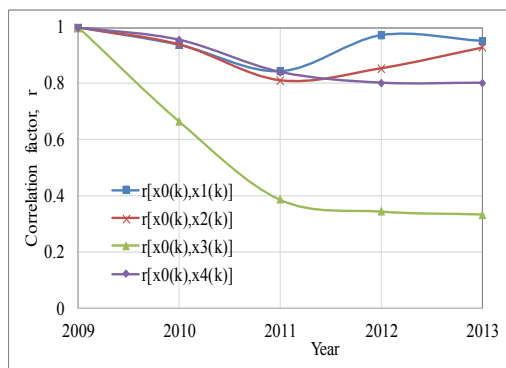
Year	2008	2010	2011	2012	2013
Annual oil production rate of single well (x0), t/a	8265.5	6727.8	1998.2	111	185.1
Annual liquid production rate of single well (x1), t/a	9366.8	10126	9234.4	1193.4	3737.8
Liquid production velocity of unit (x2), %	9.62	10.34	11.31	6.72	4.49
Water-cut of single well (x3), %	11.76	33.56	78.36	90.7	95
Thickness of oil layer (x4), m	3.8	3.8	3.8	3.8	3.8

Table 2. Grey correlation coefficient and grey correlation degree of well P2-P89 (take oil production rate of single well as the reference array).

Year	2008	2010	2011	2012	2013	$r(x_0, x_i)$
$r[x_0(k), x_1(k)]$	1	0.9378	0.8441	0.9725	0.9145	0.9413
$r[x_0(k), x_2(k)]$	1	0.9392	0.8118	0.8546	0.9006	0.9067
$r[x_0(k), x_3(k)]$	1	0.6638	0.3855	0.3435	0.3333	0.5451
$r[x_0(k), x_4(k)]$	1	0.9559	0.8416	0.8033	0.8047	0.8807

influencing oilfield development effect of horizontal wells can be obtained.

2. For horizontal wells in Chunguang oilfield, it is supposed to maintain reasonable working system and unit liquid production velocity to prevent edge water advancing quickly and delay decline of oil production rate, and improve the development effect of horizontal wells.

**Fig. (3).** Changes of grey correlation coefficient.

CONFLICT OF INTEREST

The author confirms that this article content has no conflict of interest.

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