World Journal of Engineering and Technology, 2023, 11, 417-423
https://www.scirp.org/journal/wjet
ISSN Online: 2331-4249
ISSN Print: 2331-4222

Utilizing Dynamic Data to Quickly Evaluate Advantageous Channels and Applications

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How to cite this paper: Liu, J.G., Zhang, R., Lv, Z., Wang, M.N. and Zhang, G.H. (2023) Utilizing Dynamic Data to Quickly Evaluate Advantageous Channels and Applications. *World Journal of Engineering and Technology*, **11**, 417-423.
https://doi.org/10.4236/wjet.2023.113030

Received: May 31, 2023
Accepted: June 27, 2023
Published: June 30, 2023

Abstract

In response to the high cost and difficulty of high-speed development and testing data in offshore oil fields, this paper proposes to use the most easily available production performance data as the basis and use the grey correlation method to calculate the correlation coefficient between oil and water wells to characterize the degree of development of advantageous channels. The consistency between the calculated results of this method and the tracer test results is over 80%. Based on the fitting results, the correlation coefficient exceeds 0.74 to determine the existence of an advantageous channel. According to the research results of grey correlation method, Bohai K oilfield has completed the combined profile control and flooding measures, and the daily oil production has increased by 20 m^3/d. This method is simple, fast, and can achieve quantitative evaluation, which saves time and investment compared to offshore testing. It has strong application and reference value for the development of other offshore water injection oilfields.

Keywords

Offshore Oil Fields, Production Performance, Correlation Coefficient, Advantageous Channel, Quantitative Assessment

1. Introduction

Offshore oil fields have good reservoir properties and are generally loose sandstone reservoirs. During oilfield water injection development, due to long-term erosion and immersion of injected water, physical or chemical interactions occur with mineral and rock particles in the reservoir, causing the pores in the reservoir to become larger. Permeable layers with more expanded permeability in the formation will form advantageous channels [1] [2] [3] [4]. The advantageous channel has become the main factor affecting the development of water injection oilfields. Due to the existence of advantageous channels, the contradiction between the oilfield plane and layers intensifies, which affects the effectiveness of water injection and oil displacement. Faced with the characteristics of high-speed and efficient development in offshore oil fields, it is of great significance to easily and quickly obtain data and accurately identify the distribution of advantageous channels for improving oilfield water drive efficiency and enhancing oil recovery.

At present, domestic scholars have gradually developed various methods and theories for identifying advantageous channels in water drive reservoirs. This mainly includes the following methods: 1) well testing monitoring method, which requires recording pressure and production data, and identifying advantageous channels by establishing a well testing interpretation model; 2) Production dynamic data method, which selects dynamic characterization parameters of advantageous channels such as effective permeability of oil-water phase, liquid production index, and water absorption index [5] [6] [7] [8] Tracer testing method [9], which qualitatively evaluates the existence of advantageous channels by inferring the advance speed of the tracer based on the time it is seen in each well. It is generally believed that there are dominant channels between injection and production wells with sharp and steep tracer production curves, while there are no dominant seepage channels with gentle curves Based on a comprehensive analysis of various factors that affect large pores, Liu Yuetian *et al.* [10] [11] [12] used the fuzzy evaluation method to comprehensively handle various dynamic and static factor indicators, and established an expert system for identifying large pores in oil reservoirs. The existence and development status of large pores in oil reservoirs are identified through the comprehensive evaluation value of large pores. This method can quantitatively explain the diameter and volume of large channels based on tracer injection data and pressure difference production data.

2. Application Method

The above methods make it difficult to obtain some data when identifying advantageous channels, while offshore oil field testing operations are costly and difficult. Therefore, in response to the limited data of tracer and water injection profile testing in offshore oil fields, this article proposes to use the water production rate of oil wells and water injection rate of water injection wells as the basic data, and use the grey correlation method to calculate the correlation degree between oil and water wells to characterize the degree of development of advantageous channels. The basic data of this method is easy to obtain, and it can quickly determine the direction and development degree of advantageous channels without affecting the efficient development of offshore oil fields, providing reference guidance for the development of other high water cut offshore oil fields.

A data column that reflects the behavioral characteristics of the system serves as a reference sequence. A data column composed of factors that affect system behavior is used as a comparison sequence [13] [14].

Reference sequence:

$$Y = \left\{ Y(k) \middle| k = 1,2,3,\cdots,n \right\}; \tag{1}$$

Compare sequences:

$$X_i = \left\{ X_i(k) \middle| k = 1,2,\cdots,n \right\}, i = 1,2,\cdots,m \tag{2}$$

Different data series may have dimensional differences, which can have a negative impact on the analysis results when analyzing these data. Therefore, in general, dimensionless processing is required before analysis.

$$x_i(k) = \frac{X_i(k)}{X_i(l)}, k = 1,2,\cdots,n; i = 1,2,\cdots,m \tag{3}$$

The correlation coefficient between $x_0(k)$ and $x_i(k)$ is:

$$\xi_i(k) = \frac{\min_i \min_k \left| y(k) - x_i(k) \right| + \rho \max_i \max_k \left| y(k) - x_i(k) \right|}{\left| y(k) - x_i(k) \right| + \rho \max_i \max_k \left| y(k) - x_i(k) \right|} \tag{4}$$

$$\Delta_i(k) = \left| y(k) - x_i(k) \right| \tag{5}$$

$$\xi_i(k) = \frac{\min_i \min_k \Delta_i(k) + \rho \max_i \max_k \Delta_i(k)}{\Delta_i(k) + \rho \max_i \max_k \Delta_i(k)} \tag{6}$$

ρ is the resolution coefficient. The smaller ρ, the greater the resolution. Usually, $0 < \rho < 1$ takes different ρ values according to different situations. In general, $\rho = 0.5$ has the best resolution.

Due to the fact that the correlation coefficient in a large sample is the correlation coefficient between the reference value and the comparison value of many data points, many correlation coefficient values are not easy to compare. Therefore, an average value is taken from the correlation coefficient as a representation of the correlation degree, and its formula is as follows:

$$r_i = \frac{1}{n} \sum_{k=1}^{n} \xi_i(k), k = 1,2,\cdots,n \tag{7}$$

3. Example Calculation and Result Verification

3.1. Example Calculation

K Oilfield is located in the western sea area of Bohai Sea. The oilfield is developed by water injection with a reverse nine point well network. The reservoir properties belong to the high porosity and permeability type, and the fluid properties are good. The average formation crude oil viscosity is 4.8 mPa. s. At present, the water cut of K oilfield is as high as 95%, with a recovery rate of 40%, and it is in the "dual ultra high" development stage. Based on the above principles, the monthly water injection volume of the water injection well over the years will be used as a reference sequence, and the monthly water production volume of the production well will be used as a comparison sequence. All oil wells will be considered as a well group with the water injection well as the center. The correlation coefficients of water injection wells are calculated for each production well within the well group. Considering the impact of water injection efficiency time, the monthly water production data of the oil well is moved forward by one month for calculation. Table 1 shows the calculation results of well groups W7 and W9 in K oilfield.

3.2. Result Verification

The tracer testing data of wells W7 and W9 in K oilfield indicate that the injected water of the W7 well group mainly advances along the directions of X1, X2, X8, X13, X26, and X27 wells, with frontal velocity of 10.3 m/d, 5.0 m/d, 12.3 m/d, 6.7 m/d, 3.5 m/d, and 5.3 m/d, respectively. The trace dose of X1, X2, X8, X13, X26, and X27 wells were 0.98 mg/L, 0.87 mg/L, 1.16 mg/L, 0.98 mg/L, 0.82 mg/L, and 0.79 mg/L, respectively. The injection water of Well W9 mainly advances along the directions of Wells X2, X3, X4, X8, X10, and X15, with frontal velocity of 6.9 m/d, 8.6 m/d, 9.7 m/d, 14.2 m/d, 3.3 m/d, and 3.6 m/d, respectively. The trace dose of X2, X3, X4, X8, X10, and X15 wells were 2.76 mg/L, 3.98 mg/L, 4.47 mg/L, 3.21 mg/L, 1.64 mg/L, and 2.48 mg/L, respectively (see Table 2 for the test results).

Linear regression was performed between the correlation coefficient calculated by this method and the advancing frontal velocity of the tracer test, and the fitting coefficient reached over 80% (Figure 1), indicating that this method is accurate and reliable. Based on the experience of onshore oil fields, the presence of an advantageous channel can be determined when the frontal velocity 10 m/d. Regression is performed based on the correlation coefficient and the fitting result of the frontal velocity. If the correlation coefficient of oil and water wells reaches 0.74 or above, the presence of an advantageous channel between oil and water wells can be determined. Therefore, there are advantageous channels in the X1, X8, and X27 directions of the W7 well group in K oilfield, while there are advantageous channels in the X2, X4, and X8 directions of the W9 well group.

Table 1. Table of correlation coefficient between oil and water wells in K oilfield.

Injection well	Oil well	Correlation coefficient water injection—water production	Injection well	Oil well	Correlation coefficient water injection—water production
W7	X1	0.76	W9	X2	0.74
	X2	0.60		X3	0.63
	X8	0.79		X4	0.74
	X13	0.69		X8	0.85
	X26	0.64		X10	0.63
	X27	0.76		X15	0.63

Table 2. K oilfield tracer test result table.

Well group	Oil well with tracer visible	Trace dose (mg/L)	Frontal velocity (m/d)
W7	X8	1.16	12.3
	X1	0.98	10.3
	X13	0.98	6.7
	X2	0.87	5.0
	X27	0.79	5.3
	X26	0.82	3.5
W9	X8	3.21	14.2
	X2	2.76	6.9
	X3	3.98	8.6
	X4	4.47	9.7
	X10	1.64	3.3
	X15	2.48	3.6

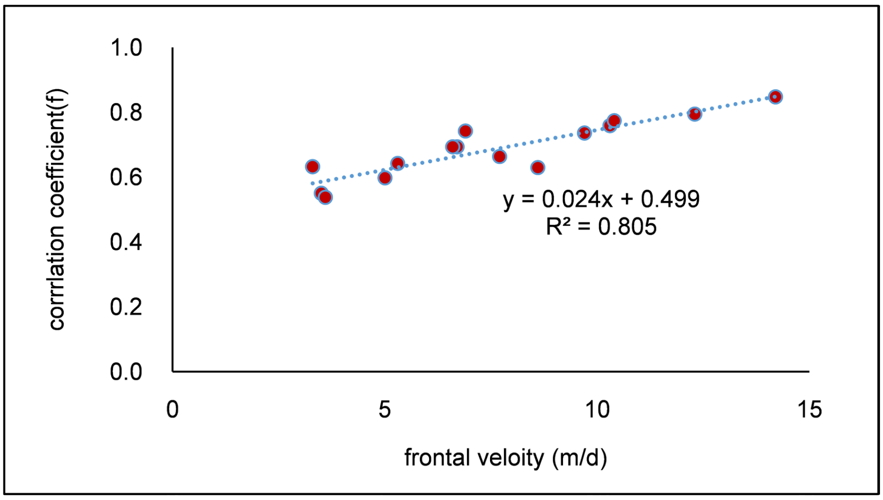

Figure 1. Relationship curve between correlation coefficient and tracer test results.

3.3. Application

Based on the identification results of advantageous channels, Bohai K Oilfield successfully implemented guidance for composite profile control and flooding in well W9. After the W9 measure, the initial daily oil increase reached 20 m^3/d, with a cumulative increase of 7724 m^3 and a decrease of 1% in water cut (Figure 2). The production parameters such as water injection absorption index and water injection pressure of the water injection well were significantly changed, and the effect of oil increase and precipitation in the affected oil well was significant. This provides new technical support for improving the development effect of old oil fields during the ultra-high water cut period.

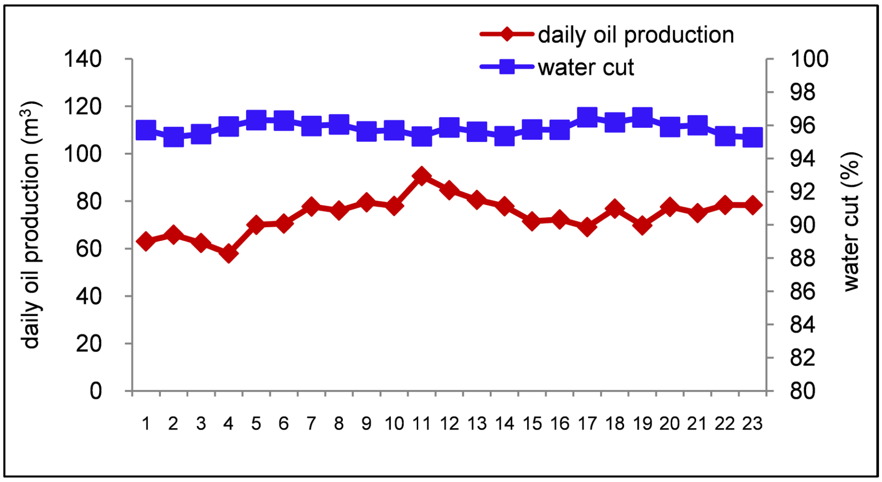

Figure 2. Effect map of W9 well group in K oilfield after composite control and flooding.

4. Conclusion

Based on the comparison of production dynamic data identification advantage channels with other conventional discrimination methods and testing data, the basic information is easy to obtain and the method is fast and quantitative. However, the impact of the production time rate of oil wells and water injection wells on the data is not considered. Please pay attention when using this method.

The reliability of the method was verified using tracer testing data, and the application of this method to guide the composite profile control and flooding of K oilfield provided important technical support for the subsequent adjustment and potential tapping of the oilfield.

Field practice has shown that this method is an effective auxiliary means for adjusting and tapping potential in the later stage of water injection oilfield development, and can provide reference guidance for similar offshore oilfield development.

Conflicts of Interest

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

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