Research on the Effect of Fracturing Construction Parameters on Tight Oil Fracturing Production Based on Grey Relational Theory

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Abstract: Tight oil is another new hot spot in global unconventional oil and gas exploration and development, following shale gas. However, the extraction effect of tight hydraulic fracturing is greatly affected by factors such as formation factors, fracturing construction parameters, and the opening time of each oil well. This article analyzes the fracturing construction parameters and selects factors such as the number of fracturing sections, fracturing fluid dosage, fracturing sand dosage, and cluster spacing as the main fracturing construction parameters for analyzing the fracturing effect, using the grey correlation method to screen out the main influencing factors in the fracturing construction parameters. The results obtained from the calculation of the correlation between each fracturing construction parameter and oil production are relatively small, with a maximum correlation of 0.1011 between cluster spacing and oil production. The calculation results indicate that the cluster spacing in the fracturing construction parameters has a relatively significant impact on the production efficiency, but the fracturing construction parameters cannot fully affect the production efficiency of tight oil.

Keywords: Tight Oil; Grey Correlation; Correlation Degree; Fracturing Construction Parameters

1. Introduction

The pore and permeability characteristics of tight oil reservoirs are extremely low, and horizontal well volume fracturing is the main technical means for tight oil reservoir exploitation. However, the selection of well and layer for fracturing has a significant impact on the effectiveness of fracturing, and there are also significant differences in different types of oil reservoirs and different well selection standards [1]. There are many factors that affect the selection of fracturing wells and layers, including geological factors, engineering factors, etc. Each factor contains multiple sub factors, and there is a certain correlation among the related sub factors. There are various methods for studying the selection of fracturing wells and layers in on-site applications. Some scholars have proposed the application of fuzzy recognition method in the selection of fracturing acidizing wells and layers, comprehensively considering multiple performance indicators of candidate well layers and calculating the weights of each performance indicator using systems engineering methods [2-4]. Scholars abroad have introduced artificial neural networks into fracturing well and layer selection, which have been widely used due to their simple principles, easy algorithm implementation, and good results. Later scholars build their research on well and layer selection for fracturing on the basis of artificial neural network models [5-7]. These methods all have different indicators as evaluation criteria, and the selected influencing factors also vary. In recent years, the use of grey correlation degree to analyze and determine the degree of influence between various factors in the system has attracted increasing attention from relevant scholars [8]. Mei [9] proposed the grey absolute correlation degree and its calculation method by analyzing the trend of time series curves between various factors; Tang [10] also proposed the type-T correlation degree and its calculation method based on the proximity of the relative change trend of the time series curve. Wang and Zhao [11,12] established a correlation analysis model by analyzing the type-B correlation degree and type-C correlation degree. Zhang and zhang [13] compared the calculation methods of typical grey correlation degree and analyzed their existing problems. Zhu et al. [14] established a grey correlation model based on grey correlation degree using Analytic Hierarchy Process. This article compares and summarizes various factors that affect the fracturing effect, calculates the proportion of each influencing factor through grey correlation analysis method, and provides the main factors that affect the post fracturing effect. Identify the parameters in the fracturing construction that have a significant impact on the production efficiency of tight oil fracturing.

2. Analysis of the Influence of Different Parameters on Oil Production

A certain research block is selected as the experimental object. The reservoir parameters of this block are shown in Table 1.

Table 1. The Influence of Formation Parameters on the Production Effect of Tight Oil Fracturing after Horizontal well Pressure

Block / Factor correlation	A	B
Sandstone thickness	12.20	14.40
Water sensitivity index	52.60	67.00
Permeability	1.23	0.50
Porosity	13.90	12.50
Formation temperature	80.00-90.00	90.00-95.00
Formation pressure	19.00	21.00
Crude oil density	0.74	0.78
Crude oil viscosity	1.45	3.20
Saturation pressure	8.90	4.60
Volume coefficient	1.23	1.11
Original gas oil ratio	67.8	39.30
Single well backflow rate	25.40	16.80

Table 2. The Influence of Fracturing Construction Parameters on the Production Effect of Tight Oil Fracturing after Horizontal well Pressure

Well number	Fracturing process	Number of fracturing sections	Fracturing fluid(m3)	Fracturing sand(m3)	Cluster spacing(m)
A- flat 1	Slicing	6	17225	505	116
A- flat 2	Slicing	10	8677	810	72
A- flat 4	Slicing	9	8488	820	90
A- flat 5	Slicing	16	13616	1258	59
A- flat 7	Slicing	13	10130	860	58
A- flat 10	Slicing	7	5766	510	81
A- flat 11	Slicing	12	9232	780	78

Through the calculation in Table 2 and Table 3, It can obtain the relationship curves between the number of fracturing stages, liquid dosage, fracturing sand dosage, cluster spacing and the oil production. Relationship curve between the number of fracturing sections and daily oil production is shown in Figure 1. Relationship curve between liquid dosage and daily oil production is shown in Figure 2. Relationship curve between fracturing sand dosage and daily oil production is shown in Figure 3. Relationship curve between cluster spacing and daily oil production is shown in Figure 4. Relationship between the number of fracturing sections and production is shown in Figure 5. Relationship curve between fracturing fluid dosage and production is shown in Figure 6. Relationship curve between fracturing sand dosage and oil production is shown in Figure 7. Relationship curve between cluster spacing and oil production is shown in Figure 8. Combining all the above data, it can be found that when using the method of directly soaking the well after fracturing for construction, the correlation between fracturing construction parameters and oil production is very small.

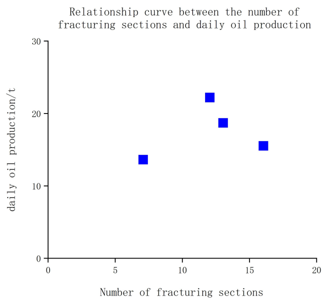

Figure 1. Relationship Curve between the Number of Fracturing Sections and Daily Oil Production

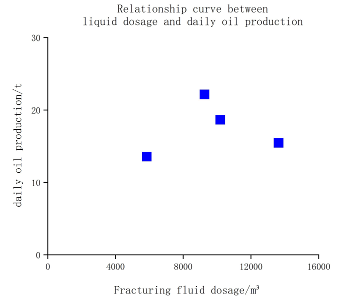

Figure 2. Relationship Curve between Liquid Dosage and daily Oil Production

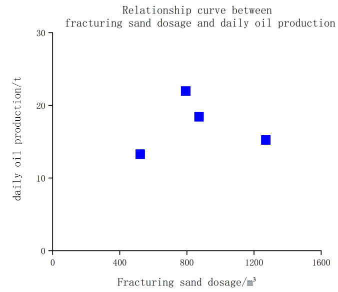

Figure 3. Relationship Curve between Fracturing Sand Dosage and Daily Oil Production

Table 3. The Influence of Different Soaking Methods on the Production Effect of Tight Oil Fracturing after Horizontal well Pressure

Well number	Soaking method	Soaking time(h)	Pressure after fracturing (MPa)	Pressure at the beginning of soaking well(MPa)	Pressure at the end of the soaking well(MPa)	Production in one year(t)
A- flat 2	Directly soak the well for 2 days after fracturing	48	14.8	14.8	14.7	4922
A- flat 5	Soak well after 15 days of fracturing	96	16.6	1.8	4.7	6115
A- flat 6	Don't soak the well after fracturing	0	18	18	18	3538

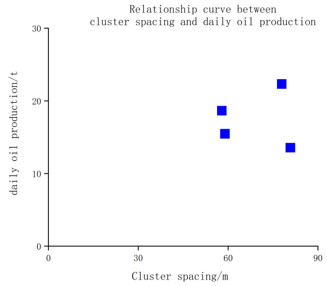

Figure 4. Relationship curve between Cluster Spacing and Daily Oil Production

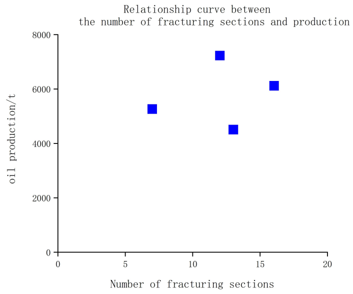

Figure 5. Relationship between the Number of Fracturing Sections and Production

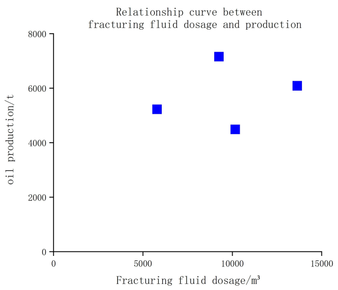

Figure 6. Relationship Curve between Fracturing Fluid Dosage and Production

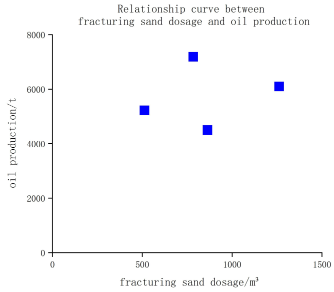

Figure 7. Relationship Curve between Fracturing Sand Dosage and Oil Production

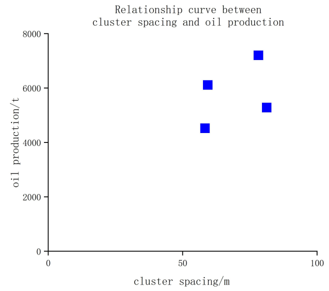

Figure 8. Relationship Curve between Cluster Spacing and Oil Production

3. Establishment of Grey Relational Model for Influencing Factors

Let the reference sequence (also known as the mother sequence) be: $Y = \{Y(k) | k = 1,2,\cdots,n\}$; comparison sequence (also known as subsequence) $X_i = \{X_i(k) | k = 1,2,\cdots,n\}$;

$i = 1,2,\cdots,m$ .This $m+1$ sequence forms a matrix:

$$\left(Y, X_1, X_2, \cdots, X_m\right)$$

Due to the fact that the data in each factor column in the system may have different dimensions, it may be difficult to compare or obtain correct conclusions during comparison. Therefore, when conducting grey correlation analysis, it is generally necessary to perform dimensionless data processing.

$$x_i(k) = \frac{X_i(k)}{X_i(l)}, k = 1,2,\cdots,n; i = 0,1,2,\ldots,m \quad (1)$$

The matrix formed after dimensionless transformation is:

$$(Y', X_1', X_2', \cdots, X_m')$$

Based on the calculation of the absolute difference between the reference sequence and the other comparison sequences, the following absolute difference matrix is formed:

$$\left(\Delta X_1(k), \Delta X_2(k), \Delta X_3(k), \cdots, \Delta X_m(k)\right)$$

Simultaneously identify the maximum number (maximum difference) and the minimum number (minimum difference) in the difference matrix.

Calculation model for correlation coefficients of various influencing factors

$$\xi_i(k) = \frac{\min_i \min_k + \rho \max_i \max_k \Delta_i(k)}{\Delta_i(k) + \rho \max_i \max_k \Delta_i(k)} \quad (2)$$

Among them, $\rho \in (0, +\infty)$ is called the resolution coefficient. ρ The smaller the size, the greater the resolution, generally ρ The value range of is (0, 1), and the specific value may vary depending on the situation. When $\rho \le 0.5463$, the resolution is the best, usually $\rho = 0.5$ is taken.

The correlation calculation formula is as follows:

$$r_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i(k), k = 1,2,\ldots,n \quad (3)$$

The grey relational model can be calculated by using the above method, and the specific process is shown in Figure 9.

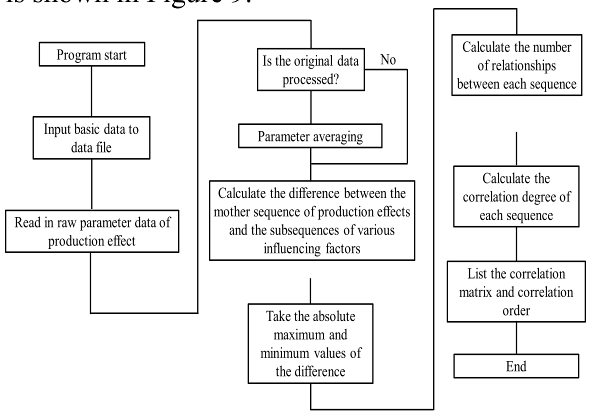

Figure 9. Flow Chart for Calculating Grey Correlation Degree

Table 4. Analysis of the Influence of Formation Factors on the Production Effect of Tight Oil Fracturing after Horizontal Well Pressure

Influence factor \ Block	A	B	A	B
Single well oil production	1454.00	94.00	1454.00	94.00
Sandstone thickness	12.20	14.40	12.20	14.40
Water sensitivity index	52.60	67.00	52.60	67.00
Permeability	1.23	0.37	1.23	0.37
Porosity	13.90	12.50	13.90	12.50
Predicted formation temperature	80.00	90.00	80.00	90.00
Predicted formation pressure	19.00	21.00	19.00	21.00
Crude oil density	0.74	0.78	0.74	0.78
Crude oil viscosity	1.45	3.20	1.45	3.20
Saturation pressure	8.90	4.60	8.90	4.60
Volume coefficient	1.23	1.11	1.23	1.11
Original gas oil ratio	67.8	39.30	67.8	39.30
Single well backflow rate	25.40	16.80	25.40	16.80
Illite	71.10	61.30	71.10	61.30
Chlorite	17.80	27.80	17.80	27.80
illite/montmorillonite	8.70	9.80	8.70	9.80

4. Instance Application

The formation parameters of Block A and Block B are shown in Table 4. Analysis of the influence of formation factors on the production effect of tight oil fracturing after horizontal well pressure.

The original data changes and a single well oil production is set as the mother factor sequence, denoted as x0, then

$$x_0=(1454,94)$$

At the same time, sandstone thickness, water sensitivity index, permeability, porosity, predicted formation temperature, predicted formation pressure, crude oil density, crude oil viscosity, saturation pressure, volume coefficient, original gas oil ratio, single well flowback rate, illite content, chlorite, and illite/montmorillonite content are sub factor sequences, which are recorded in sequence as x1,x2,…,x15.

4.1 Determine the Sequence Matrix for Analysis

Table 5 shows the data of fracturing construction parameters for a certain block in Daqing Oilfield, which were measured under the conditions of determining other parameters.

Table 5. Fracturing Construction Parameters of Block A

Well number	Number of fracturing sections	Fracturing fluid (m3)	Fracturing sand (m3)	Cluster spacing(m)	Oil production in one year(t)
A- flat 5	12	13616	1158	45	4815
A- flat 7	10	10130	860	58	4513
A- flat 10	8	3766	510	75	5256
A- flat 11	14	4232	380	78	5021

According to the data in Table 5, taking the oil production after one year as the reference sequence (y), and comparing the fracturing construction parameters such as the number of fracturing sections x1, fracturing fluid x2, fracturing sand x3, and cluster spacing x4, the analysis matrix can be determined as $\left(y, x_1, x_2, x_3, x_4\right)$

4.2 Dimensionless Processing Transformation of Variable Sequences

According to equation (1), dimensionless processing the basic data in Table 1, and the resulting data is shown in Table 6.

Table 6. List of Dimensionless Processing Numbers

Well number	Number of fracturing sections	Fracturing fluid	Fracturing sand	Cluster spacing	Oil production in one year
A- flat 5	1.3333	1.4057	1.4765	0.8551	1.0592
A- flat 7	1.0833	1.0458	1.0094	0.8406	0.7817
A- flat 10	0.5833	0.5953	0.5986	1.1739	0.9104
A- flat 11	1	0.9531	0.9531	1.1304	1.2486

4.3 Finding the Difference Sequence, Maximum Difference, and Minimum Difference

Calculate the absolute difference between the comparison sequence of the same well and the reference sequence, and obtain the result of the absolute difference between each parameter and the oil production after one year as shown in Table 7.

Table7. Absolute Difference Calculation Table

Well number	Δx1(k)	Δx2(k)	Δx3(k)	Δx4(k)
A- flat 5	0.2741	0.3465	0.4173	0.2041
A- flat 7	0.3016	0.2641	0.2276	0.5884
A- flat 10	0.3271	0.3152	0.3119	0.2635
A- flat 11	0.2486	0.2954	0.3331	0.1181

According to the data in the above table, the maximum value is $M = 0.7333$ and the minimum value is $m = 0.0145$.

4.4 Calculate Correlation Coefficient

If the resolution coefficient is taken as $\rho = 0.1$, then the correlation coefficients of each influencing factor can be obtained according to equation (2), as shown in Table 8.

Table 8. Calculation of Correlation Coefficients

Well number	ζ1(k)	ζ2(k)	ζ3(k)	ζ4(k)
A- flat 5	0.1044	0.0599	0.0654	0.0868
A- flat 7	0.1179	0.0807	0.0883	0.1175
A- flat 10	0.0815	0.0661	0.0796	0.1055
A- flat 11	0.0895	0.0718	0.0711	0.0947

4.5 Calculate Correlation Degree

According to the correlation coefficients in Table 8, use equation (3) to calculate the correlation degree of each influencing factor as shown in Table 9.

Table 9. Calculation Results of Correlation Degree

Name	Γ1	Γ2	Γ3	Γ4
Correlation degree	0.0933	0.0696	0.0761	0.1011

4.6 Sort Association Order

According to the obtained correlation degree, it can be concluded that:

$$r_4 > r_1 > r_3 > r_2$$

5. Establish a Method for Evaluating the Effectiveness of Tight Oil Fracturing after Horizontal well Pressure

Table 10. Stratigraphic Parameters of Block A and Block B in Daqing Oilfield

Sandstone thickness	x1=(12.2,14.4)
Water sensitivity index	x2＝(52.6,67)
Permeability	x3＝(1.23,0.37)
Porosity	x4=(13.9,12.5)
Predicting formation temperature	x5=(80,90)
Predicting formation pressure	x6=(19,21)
Crude oil density	x7=(0.74,0.78)
Crude oil viscosity	x8=(1.45,3.2)
Saturation pressure	x9=(8.9,4.6)
Volume coefficient	x10=(1.23,1.11)
Original gas oil ratio	x11=(67.8,39.3)
Single well flowback rate	x12=(25.4,16.8)
Illite	x13＝(71.1,61.3)
Chlorite	x14＝(17.8,27.8)
illite/montmorillonite	x15＝(8.7,9.8)

There are two methods for transforming the raw data in Table 10 to make it dimensionless and unified: one is Equalization, and the other is Initialization. Equalization is generally used for relatively scattered data sequences and can to some extent reduce the impact caused by the instability of the first data. Initialization is generally used for data sequences with an increasing trend. During this study, the data sequence was scattered, and the data was processed using Equalization. Then calculate the correlation coefficient to determine the degree of correlation.

The data processing and calculation process can be programmed using VB, and the above sequence can be substituted into the program to obtain the correlation degree between each sub factor and the parent factor

G(1,1)= 0.4892;G(1,2)= 0.4810;
G(1,3)= 0.6334;G(1,4)= 0.5211;
G(1,5)= 0.4945;G(1,6)= 0.5540;
G(1,7)= 0.5019;G(1,8)= 0.4319;
G(1,9)= 0.5373;G(1,10)= 0.5206;
G(1,11)= 0.5805;G(1,12)= 0.4967;
G(1,13)= 0.5264;G(1,14)= 0.4608;
G(1,15)= 0.4943;

Ranking the correlation degree of each factor yields:

G(1,3)>G(1,11)>G(1,6)>G(1,9)>G(1,13)>G(1,4)>G(1,10)>G(1,7)>G(1,12)>G(1,5)>G(1,15)>G(1,1)>G(1,2)>G(1,14)>G(1,8)

In summary, among the geological factors, factors such as permeability, original gas oil ratio, formation pressure, saturation pressure, and the content of illite in the formation have a more significant impact on the production effect of tight oil fracturing after horizontal well pressure. However, factors such as crude oil viscosity and water sensitivity index don’t have a significant impact on the fracturing effect.

6. Conclusions

Through the correlation analysis model, the dimensionless treatment of fracturing construction parameters in tight reservoirs was carried out, and the correlation degree between each parameter and oil production was calculated. The results obtained were all between 0.05 and 0.15, indicating that fracturing construction parameters are not the main controlling factor affecting the effectiveness of tight oil fracturing construction, but still have a certain impact on oil production. By arranging the correlation order, it can be obtained that among the four parameters of the number of fracturing sections, fracturing fluid, fracturing sand, and cluster spacing, the correlation between cluster spacing and oil production is the highest, at 0.1011. Therefore, in the fracturing construction parameters, the size of cluster spacing has the most significant impact on the post fracturing production effect. However, due to the current incomplete fracturing technology, there are still a series of technical problems in the fracturing process. Therefore, further analysis is needed when analyzing the impact of fracturing parameters on oil production efficiency.

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References

[1] Sifeng Liu, Hua Cai, Yingjie Yang, et al. Research progress on grey relational analysis models. Systems engineering theory and practice, 2013, 33(8): 2041-2046.

[2] Zuoan Sun and Qi Wang, The role of resolution coefficient and its determination method, Journal of Liaoning University of Technology, 1997(4): 79-82

[3] Feng Lü, Research on the Resolution System of Grey System Correlation Degree, Systems Engineering Theory and Practice, 1997, 17(6): 49-54

[4] Kai Fan and Haoying Wu, A New Method for Determining Resolution Coefficients in Grey System Correlation Degree, Journal of Wuhan University of Technology, 2002, 24(7): 86-88

[5] Zhengzhang Zhao and Jinhu Du. Tight Oil and Gas. Beijing: Petroleum Industry Press, 2012: 2-12

[6] Yu Shi, Boxue Wang, Haitao Wei et al. Current Status and Development Suggestions of Tight Oil Fracturing. Inner Mongolia Petrochemical, 2014, 22: 133-135.

[7] Xinmei Liu, Runfang Xu, Ruoyong Zhang et al. Application Model of Deng's Grey Relational Analysis. Statistics and Decision Making, 2008, 20: 23-25

[8] Julong Deng. Grey System Theory Tutorial. Wuhan: Huazhong University of Science and Technology Press, 1990.

[9] Zhenguo Mei, Grey Absolute Correlation Degree and Its Calculation Method, Systems Engineering, 1992, 10(5): 43-44

[10] Wuxiang Tang, type-T correlation degree and its calculation method, Mathematical Statistics and Management, 1995, 14(1):34-37

[11] Qingyin Wang, Grey type-B Correlation Analysis, Journal of Huazhong University of Science and Technology, 1987, 17(6): 77-82

[12] Qingyin Wang and Xiuheng Zhao, type-C correlation analysis, Journal of Huazhong University of Science and Technology, 1999, 27(3): 75-77

[13] Shaoliang Zhang and Guoliang Zhang, Comparison of Grey Relational Degree Calculation Methods and Analysis of Existing Problems, Systems Engineering, 1996, 14(3): 45-49

[14] Hugen Zhu, Jiaquan Wang, Chengqing Wu, et al. Grey relational model in hierarchy analysis process, The Journal of Grey System, 1993, 5(3): 221-234

