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Evaluating Casing Damage Basing on Fuzzy Comprehensive Evaluation and Grey Relational Grade Analysis

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Abstract

Casing damage is one of the main factors influencing oil production, and determined the main factors which lead to casing damage is the premise to develop effective prevention and control measures of casing damage. The relationship between various factors of casing damage is complicated, and it is difficult to determine the main factors influenced the casing damage applying for conventional theoretical analysis and quantitative calculation. In this paper, the main factors influenced casing damage is evaluated by the method of combination fuzzy comprehensive evaluation and grey relational grade analysis. Firstly, this article analyzed factors causing casing damage, and then evaluated 22 wells of Daqing oilfield which is located in the west block of the Southern District fault. Comparing the evaluation and the actual results, the accuracy rate of this model is 86.3%, and showing that the evaluation results are accurate and reliable.

Key words: Casing damage; Fuzzy comprehensive evaluation; Grey relational grade; Effect evaluation

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INTRODUCTION

Along with development of water-flooding, the number of wells with casing damage is increasing. Casing damage directly affects on cost and oil production schedule, and it will reduce the oil yield and make the whole well abandoned, and even disturb oilfield development plan[1-3]. Measures from drilling to development, and in the process of oil extraction process impacted on the casing damage[4], and the stress of casing of the whole process is very complex. So reasons of casing damage related to geology, development and other aspects[5]. These factors interrelate and restrict each other, forming a complex system, and it is difficult to make an evaluation on the problem of casing damage.

This paper puts forward a method of combining fuzzy comprehensive evaluation and grey correlation degree analysis to synthetically evaluate the problem of casing damage. Grey correlation analysis is a kind of analysis method of gray system, applying for the statistical analysis of multivariate, solving degree of relevance among various factors in nonlinear problem, and determining importance of multiple factors, and then confirm the weight of various impact factors Fuzzy comprehensive evaluation is to make the synthetically evaluation of problem and phenomenon influenced by various factors, but it lacks foundations to determining the weight of multiple factors. In this paper, the application of the grey correlative degree grey incidence coefficient of casing damage is calculated, and determine the importance order of various factors, obtaining the weights index of factors applying to fuzzy comprehensive evaluation and then the application of fuzzy comprehensive evaluation evaluate the problem of casing damage.

1. ANALYSIS OF CASING DAMAGE FACTORS

1.1 Analysis of Geological Factors

Geological factors of casing damage included faults, lithology, water sensitive index, permeability, porosity and so forth[6]. The survey found that the number of casing failure wells near the fault is more than the area with no fault. The main reason of casing damage is that with the development of water flooding, formation pressure changing, the crustal subsidence and ascension speed is different, and make the fault activate, causing the upper and lower formation relative slip and shearing casing. Due to the presence of faults, formation will more prone to lateral move and then shear casing, leading to casing damage. Water sensitivity index acting on casing damage is affected by the physical property of reservoir, making the reservoir permeability change, and inducing formation pressure to change, and thus acting on the casing. The development of Water flooding, resulting in reservoir physical property poor, increased injection pressure and make the reservoir stayed the condition of high pressure in the long term. Porosity acting on the casing is that the development of water flooding caused the formation pressure change, and then made reservoir bed thickness revise and formation deformation aggravated the damage of casing, porosity having great influence on the alteration of sandstone thickness.

1.2 Analysis of Development Factors

Development factors of casing damage included injection pressure, injection allocation, the time of top of breakdown pressure[7]. High injection pressure often makes formation stay in the condition of high pressure in the long term, the build-up reservoir pressure causing the sandstone matrix expansion, and reservoir thickness increases. The section of casing through the oil layer stretched accordingly, and thus made casing generated large additional tensile stress and the collapsing strength of casing decreased and casing was more prone to shear damage. In general, water injection with the top breakdown pressure require high-impact casing, but we did not consider this situation in the process of casing string design. It is a gross test of casing which stayed in the top breakdown pressure for the longest time. Disorder of the sublayer water intake and injection allocation anomalies can cause casing damage. As to high shale content area, rock strata absorbing water causes rock creep, overburden weight acting on the casing, and the casing damage is prone to occur.

1.3 Analysis of Engineering Factors

Engineering factors resulting in casing damage contain perforation, well cementation, corruption, stimulation treatment and so forth[8]. The instantaneous impact force of perforation makes casing detriment and aggravate climate of casing damage. Times of oil well acidification, acidification fluid will accelerate the corrosion rate of casing and make casing perforate and leak out. The cementing quality also affects on the service life of casing pipe, for example, poor cementing quality of water wells aggravating velocity of the injected water drifting into the rock. Late development of stimulation treatments will generally make the formation pressure increase rapidly, and result in a large amount of casing damage.

Consequently, influence factors of casing damage include lithology, fault, water sensitivity index, permeability, porosity, water injection pressure, injection allocation, staying top breakdown pressure times, cementing, perforation, corrosion, stimulation treatment and so forth. The following will be apply gray correlation analysis and fuzzy comprehensive evaluation to analyze the problem of casing damage.

2. THE THEORETICAL CALCULATION MODEL OF GREY CORRELATION ANALYSIS AND FUZZY COMPREHENSIVE EVALUATION

2.1 Deduction of Grey Relational Analysis Theoretical Calculation Model

The fundamental principle of grey correlation analysis is based on the similar degree of sequence curve geometry to determine its relation. Two curves are more similar to each other, degree of association is more greater among corresponding sequences, whereas it is smaller. Application of grey correlation degree analysis estimates degree of association among factors and casing damage and obtain the weight of each influence factor[9].

First, to establish the characteristics of sequence effecting on the phenomenon or problem (the mother sequence) X_0.

$$X_0 = \{x_0(1), x_0(2), \cdots, x_0(n)\} \tag{1}$$

Second, to make influence factors as comparative sequence (sub column) X_i,

$$X_i = \{x_i(1), x_i(2), \cdots, x_i(\mathrm{n})\} \tag{2}$$

Type is that X_i is the first i factor for the phenomenon or problem.

Third, to make the reference matrix and comparative sequence as matrix w, denoted as A.

$$A = \left[X_0, X_1, \cdots, X_m\right]^T = \begin{bmatrix} x_0(1) & x_0(2) \cdots & x_0(\mathrm{n}) \\ x_1(1) & x_1(2) \cdots & x_1(n) \\ \vdots & \vdots & \vdots \\ x_m(1) & x_m(2) \cdots & x_m(n) \end{bmatrix} \tag{3}$$

Fourth, to make the variables alter to the dimensionless variables, applying homogeneous dimensionless method to calculate the initial value matrix, denoted as matrix A'.

$$A' = \begin{bmatrix} x_0'(1) & x_0'(2) \cdots & x_0'(\mathrm{n}) \\ x_1'(1) & x_1'(2) \cdots & x_1'(n) \\ \vdots & \vdots & \vdots \\ x_m'(1) & x_m'(2) \cdots & x_m'(n) \end{bmatrix} \tag{4}$$

Type is that the element of line i article j is $x_i'(j) = \dfrac{x_i(j)}{\frac{1}{10}\sum_{k=1}^{10} x_i(k)}$.

Fifth, to calculate the absolute difference between reference sequence and comparative sequence and acquire difference sequence matrix. The general calculating formula for the matrix difference sequence is that

$$\Delta A = \begin{bmatrix} \Delta x_1(1) & \Delta x_1(2) \cdots & \Delta x_1(n) \\ \Delta x_2(1) & \Delta x_2(2) \cdots & \Delta x_2(n) \\ \vdots & \vdots & \vdots \\ \Delta x_m(1) & \Delta x_m(2) \cdots & \Delta x_m(n) \end{bmatrix} \quad (5)$$

Type is that the element of line i article j is $\Delta x_i(j) = \left| x_i^{'}(j) - x_0^{'}(j) \right|$.

Sixth, according to the difference sequence matrix, compute the level two maximum difference and minimum differential of the difference sequence matrix, and its general formula is that

$$\begin{cases} \text{Max} = \max\limits_i \max\limits_k \left\{ \Delta x_i(k) \right\} \\ \text{Min} = \min\limits_i \min\limits_k \left\{ \Delta x_i(k) \right\} \end{cases} \quad (6)$$

Seventh, based on above calculation, calculate the correlation coefficient matrix. The general formula of Correlation coefficient matrix is that

$$\Upsilon = \begin{bmatrix} \gamma_1(1) & \gamma_1(2) \cdots & \gamma_1(n) \\ \gamma_2(1) & \gamma_2(2) \cdots & \gamma_2(n) \\ \vdots & \vdots & \vdots \\ \gamma_m(1) & \gamma_m(2) \cdots & \gamma_m(n) \end{bmatrix} \quad (7)$$

Type is that the element of line i article j is $\gamma_i(j) = \dfrac{\text{Min} + \xi \text{Max}}{\Delta x_i(j) + \xi \text{Max}}$, and $\gamma_i(j)$ is the correlation coefficient of line i article j, and x is resolution ratio, and x is generally between 0 and 1 and this paper x extracting 0.5.

Finally, to calculate the degree of grey correlation coefficient of various factors, and its general formula is that:

$$\gamma_i = \frac{1}{n} \sum_{k=1}^{n} \gamma_i(k) \quad (8)$$

Type is that γ_i is the grey correlation coefficient of the first i factor, i = 1, 2, …, n.

According to above calculation, the grey correlation coefficient can decide the importance of influence factors, based on the importance sort influence factors, and then according to the grey correlation coefficient determine the weight value of each influence factor. The calculation formula of weight values of influence factors is that

$$\omega_i = \frac{\gamma_i}{\sum\limits_{k=1}^{10} \gamma_k} \quad (9)$$

Type is that w_i is the weight of the first i factor, i = 1, 2, …, m.

2.2 A Theoretical Computational Model of Fuzzy Comprehensive Evaluation

Fuzzy comprehensive evaluation is to make comprehensive evaluation of the problem or phenomena influenced by multiple influence factors, namely according to conditions, and evaluated the object, given each object a non-negative real number, and then according to the model of fuzzy comprehensive evaluation sorted and preferred. Comprehensive evaluation can be divided into a comprehensive evaluation and grade two and above comprehensive evaluation. This paper adopts a comprehensive evaluation on analyzing and evaluating the phenomenon of casing damage[10-11].

Firstly, according to the phenomenon or problem, determine the evaluation index set and denote as U.

$$U = \{u_1, u_2, \cdots u_i \cdots, u_m\} \quad (10)$$

Type is that u_i is the first i influence factor, i = 1, 2, …, n.

Second, to determine the influence weight of each influence factor. The main methods to determine the weights contain analytical hierarchy process, statistical analysis method, entropy method and etc. But determine the weight of influence factors value by the method of AHP will have individual subjectivity. The statistical analysis method needs a large amount of data, and lack of data is difficult to find out the rule or if data lacks representativeness it will cause the relationship and rules distorted and reversed. The entropy method also requires amounts of data and absence of information increase uncertainty. The grey correlation degree analysis is applicable for the number and rules of sample, and amount of calculation is small, and especially the result of evaluation is objective, accurate. Index weight is W.

Third, to determine the evaluation set. According to the phenomenon or problem, divide evaluation set, denoted as V.

$$V = \{v_1, v_2, \cdots, u_k\} \quad (11)$$

Fourth, to determine the membership matrix. The membership degree matrix makes influence factors normalized, and all elements in the matrix values are between 0 and 1. The value is closer to 1 showed that the value is effecting on the phenomenon or problem has great influence on consequence, and the value is the closer to 0 shows that the factor has less influence on consequence. The membership matrix is as follows, denoted as R.

$$R = \begin{bmatrix} r_{11}^{'}, r_{12}^{'} \cdots, r_{1n}^{'} \\ r_{21}^{'}, r_{22}^{'} \cdots, r_{2n}^{'} \\ \cdots \\ r_{m1}^{'}, r_{m2}^{'} \cdots, r_{mn}^{'} \end{bmatrix} \quad (12)$$

The calculation formula of influence factors closed to 1 is as follows.

$$r_{ij}' = \frac{r_{ij} - r_{i\min}}{r_{i\max} - r_{i\min}}$$

Type is that r'_{ij} is the degree of membership of line i article j, and r_{ij} is the value of line i article j, and $r_{i\max}$, $r_{i\min}$ are respectively the maximum and minimum of overall data.

The calculation formula of influence factors closed to 0 is as follows.

$$r_{ij}' = 1 - \frac{r_{ij} - r_{i\min}}{r_{i\max} - r_{i\min}}$$

Finally, calculate fuzzy comprehensive evaluation. Through the matrix operation between the membership matrix R and the weight set W of evaluation index, we can be obtained the evaluation result of B.

$$B = W \circ R \tag{13}$$

Type is that ° is the fuzzy operator.

3. THE EXAMPLE CALCULATION

Taking 20 water or oil wells in Daqing oilfield located in West block in Southern Ⅰ District fault as an example, this paper proposes that application of evaluation method predicts and evaluates each well casing damage or not, compared with the actual, and demonstrates the applicability of the model.

The weight of influence factors of casing damage is determined by application the method of grey correlation degree analysis. The influence factors effecting on casing damage contains fault, lithology (based on shale content), water sensitive index, permeability, porosity, water injection pressure, injection allocation, staying top breakdown pressure times, cementing, perforation, corrosion, the number of corruption perforation, stimulation treatment (mainly determined by fracturing number) and so forth. Count for 20 water or oil wells data in Daqing oilfield located in West block in Southern Ⅰ District fault and calculate weight of each influence factors of casing damage. The following is Table 1.

According to the calculation steps of gray correlation degree analysis, we confirmed the weight of various influence factors of casing damage, as Table 2. Assumed the values of the reference sequence set is that the casing damage wells is 0, otherwise is 1.

Table 1
The Value of Factors Effecting on Casing Damaged Weight in the Southern Ⅰ District

Factors	Fault	Shale content	Water sensitivity index	Permeability	Porosity	Waterflood pressure	Time	Fracturing number
Weight *W*	0.022	0.066	0.116	0.153	0.232	0.204	0.120	0.087

Table 2
The Membership Matrix of N1-D1-26 Well

Num	Factors	Parameter	Membership matrix *R*		
1	Fault	2	0.3567	0.2563	0.3498
2	Shale content /%	5.6	0.4621	0.5421	0.3214
3	Water sensitivity index	0.58	0.7532	0.5123	0.2546
4	Permeability	53	0.3145	0.4154	0.3314
5	porosity	0.32	0.3794	0.3416	0.254
6	Waterflood pressure /MPa	11.0	0.7894	0.2145	0.3146
7	Time /Day	88	0.221	0.3369	0.7854
8	Fracturing number	7	0.4516	0.3458	0.2345

Application of fuzzy comprehensive evaluation model to evaluate the 20 wells in the instance. First, determine the evaluation set V = {small risk, risk, risk big}. Then calculate the membership matrix of N1-D1-26 according to the formula. As is shown in Table 2.

The grey correlation analysis to determine the weight value for responding is W = [0.022, 0.066, 0.116, 0.153, 0.232, 0.204, 0.120, 0.087].

The calculation of fuzzy evaluation for well N1-D1-26 value is B = {0.4887, 0.3579, 0.3649}, according to the formula belongs to the risk of large wells, the well casing damage wells with fuzzy evaluation results consistent. Other wells casing damage evaluation results in Table 3 and the actual casing damage compared to see.

From Table 3 comparison results can be seen, the rate of accuracy evaluation model to achieve 86.3%, 2 wells only evaluation results of wells in error, inaccurate, analyze the reasons may be due to perforation, corrosion or other measures to increase the role of casing, make its appear damaged. Through the application of the block to prove that the evaluation model has good adaptability and accuracy, can be used to analyze the main factors which influence the other block of casing damage, so as to effectively develop the casing damage prevention and control plan.

Table 3
Fault Block the Southern District West of Casing Damage Evaluation Results and the Actual Casing Damage Comparison

Well Num	Evaluation result	Actual result	Accuracy	Well num	Evaluation result	Actual result	Accuracy
N1-D1-26	Big risk	Damage	Accurate	N1-2-B025	Small risk	Damage	Wrong
Z91-20	Small risk	Non damage	Accurate	N1-D3-F30	Big risk	Damage	Accurate
Z9-121	Big risk	Damage	Accurate	G162-443	Big risk	Damage	Accurate
Z92-21	Big risk	Damage	Accurate	N1-D2-W124	Big risk	Damage	Accurate
Z92-222	General risk	Damage	Wrong	N1-2-B026	Big risk	Damage	Accurate
Z102-19	Big risk	Damage	Accurate	G160-39	Big risk	Damage	Accurate
Z10-D21	Big risk	Damage	Accurate	N1-1-D23	Big risk	Damage	Accurate
N1-21-13	Big risk	Damage	Accurate	N1-2-FB22	Small risk	Non damage	Accurate
G153-34	Small risk	Non damage	Accurate	N1-22-19	Big risk	Damage	Accurate
Z91-18	Small risk	Non damage	Accurate	N1-1-B21	Small risk	Non damage	Accurate
N1-1-32	Big risk	Damage	Accurate	N1-2-D27	General risk	Damage	Inaccurate

CONCLUSION

In this paper, based on the grey system theory and fuzzy mathematics theory, the application of gray correlation analysis and fuzzy comprehensive evaluation method was established to determine the main factors causing casing damage model, the calculation results of the example show that the calculated results agree well with the actual situation of the line. This model can be used to determine the main factors in different blocks of casing damage, so as to develop effective prevention and control measures for causing damage in different blocks, on the prevention of guiding significance of casing damage.

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