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Based on the gray system theory for predicting oilfield cementing quality

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Abstract: This paper introduces the basic principles of the gray system theory and the GM(1, N) model, and analyzes the factors affecting of the cementing quality. This paper selects nine major factors and dimension reduction by principal component analysis. Using the data after dimension reduction to establishment of gray system model to predict the quality of cementing, the simulation and prediction of the oil cementing the actual data is carried out by this method. The results show that the algorithm is stable, fast, and accurate forecasting, suitable for real-time requirements are relatively high occasions.
Keywords: Gray System; cementing quality; prediction

INTRODUCTION

In all aspects of oil drilling, cementing operations play an important role in the overall drilling. There are many factors that affect the quality of cementing[1,2], and these factors influence each other, mutual restraint, either alone, or in combination affect the role of cementing quality. Therefore, to carry out multivariate analysis on the quality of cementing, to explore the influence of various factors drilling, cementing process and geological conditions, such as blocks of cementing quality. Prediction model we have established between the factors and cementing quality, predicted cementing quality and timely correction cementing program based on forecast results, thus improving the quality of cementing. Now, research on theories and models to predict the quality of cementing is not a lot. Gray system can use little data, extracting valuable information to achieve operational behavior of the system, the correct description of the evolution. In this paper, cementing quality gray prediction model established by the gray system theory, get a better prediction.

GRAY GM (1, N) MODEL

In 1982, the gray system theory founded by Chinese scholar Professor Deng Julong is a new method for small data, poor information and uncertainties. Grey system theory[3,4] as "part of the information known, some information is unknown, " the "small sample", "poor information" uncertain system for the study, the main part of the known information through the generation, development and extraction of valuable information to achieve runtime behavior of the system, the correct description of the evolution and effective monitoring. Gray System Model has no special requirements and restrictions for the experimental observations, therefore, it has a very wide range of applications.

Set $x_1, x_2, \cdots, x_N$ are n-dimensional vector, that is

$$x_i^{(0)} = \left(x_i^{(0)}(1),\quad x_i^{(0)}(2),\quad \cdots \quad x_i^{(0)}(3) \right) \qquad i = 1, 2, \cdots, N$$

For $x_i^{(0)}$ make one accumulated generating

$$x_i^{(1)}(k) = \sum_{t=1}^{k} x_i^{(0)}(t)$$

For $x_i^{(1)}$ establish explicit form of differential equations

$$\frac{dx_1^{(1)}}{dt} + a x_1^{(1)} = b_1 x_2^{(1)} + b_2 x_3^{(1)} + \cdots + b_{N-1} x_N^{(1)}$$

Parameter list of the above equation is denoted by $\hat{a}$

$$\hat{a} = (a, b_1, b_2, \cdots, b_{N-1})^T$$

General solution of this differential equation is：

$$x_1^{(1)}(t) = [x_1^{(1)}(t_0) - \frac{\sum_{i=2}^{N} b_{i-1} x_i^{(1)}(t)}{a}]e^{-ak} + \frac{\sum_{i=2}^{N} b_{i-1} x_i^{(1)}(t)}{a}$$

The known number of columns x_i substituted into equation, can be solved by the least squares method parameter $\hat{a}$, you can get the general solution.

Parameters $\hat{a}$ can be solved by the least squares method, the formula is:

$$\hat{a} = (B^T B)^{-1} B^T y_N$$

$$B = \begin{pmatrix} -\frac{1}{2}(x_1^{(1)}(1) + x_1^{(1)}(2)) & x_2^{(1)}(2) & \cdots & x_N^{(1)}(2) \\ -\frac{1}{2}(x_1^{(1)}(2) + x_1^{(1)}(3)) & x_2^{(1)}(3) & \cdots & x_N^{(1)}(3) \\ \vdots & & & \\ -\frac{1}{2}(x_1^{(1)}(n-) + x_1^{(1)}(n)) & x_2^{(1)}(n) & \cdots & x_N^{(1)}(n) \end{pmatrix}$$

$$y_N = (x_1^{(0)}(2), x_1^{(0)}(3), \cdots, x_1^{(0)}(n))^T$$

Get the GM (1, N) gray prediction equation is:

$$\hat{x}_1^{(1)}(k+1) = [x_1^{(1)}(1) - \frac{1}{a}\sum_{i=2}^{N} b_{i-1} x_i^{(0)}(k+1)]e^{-ak} + \frac{1}{a}\sum_{i=2}^{N} b_{i-1} x_i^{(1)}(k+1)$$

Among them

$$x_1^{(1)}(0) = x_1^{(1)}(1)$$

The analog value $x_1^{(1)}$ which is calculated in accordance with the model, the following equation is reduced to $x_1^{(0)}$

$$\hat{x}_1^{(0)}(k+1) = \hat{x}_1^{(1)}(k+1) - \hat{x}_1^{(1)}(k)$$

The difference between analog value and the actual value is called residuals

$$e(k) = \hat{x}_1^{(0)}(k) - x_1^{(0)}(k) \qquad k = 1, 2, \cdots, n$$

When the residuals meet the accuracy requirements, the model can be used to predict the system.

When GM (1, N) model established by the original data $x_1, x_2, \cdots, x_N$ test failed, you can establish GM (1,1) model with residuals e, amendments to the original model.

CEMENTING QUALITY FORECAST

Now take the North 1 of Daqing oilfield 96 well data (see Attached Table 1) as a sample, the establishment of gray system model.

Many factors influence the quality of cementing, here we take nine major factor x_i ($i = 1, 2, \cdots, 9$), respectively, formation pressure coefficient, permeability, well diameter enlargement ratio, borehole diameter rules, fluid density, drilling fluid shear, slurry density casing centering degree, for speed. First, the principal component analysis to reduce the dimension of these nine factors. After calculation model input vector dimension reduced from nine to three-dimensional dimension (see Table 2 data), the three new variable named geological factors, factors drilling, cementing factor.

Choose 86 data as training data model, separated from the 96 data, the remaining 10 data as the test data used to test the trained models.

Establish cementing quality prediction gray GM (1,4) model. Hutchison cementing quality, geological factors y_1, factors drilling y_2, cementing factors y_3 were four parameters listed are $x_1, x_2, \cdots, x_4$.

cementing quality: $x_1^{(0)} = (100, 80, 40, 70, 70, \cdots\cdots)$

geological factors y_1: $x_2^{(0)} = (7.8809, 7.0445, 8.0875, 7.6721, 9.2034 \cdots\cdots)$

factors drilling y_2: $x_3^{(0)} = (1.4169, 1.3779, 1.0586, 1.8571, -0.5759 \cdots\cdots)$

cementing factors y_3: $x_4^{(0)} = (1.0480, -0.2445, -0.7258, 1.1819, 0.2470 \cdots\cdots)$

For data $x_1^{(0)}, x_2^{(0)}, x_3^{(0)}, x_4^{(0)}$ accumulated generating $x_1^{(1)}, x_2^{(1)}, x_3^{(1)}, x_4^{(1)}$,establish explicit form of differential equations, solver parameters a, b_1, b_2, b_3,

$$a = 0.24502, \quad b_1 = 2.95898, \quad b_2 = -1.50027, \quad b_3 = 1.59653$$

Get the GM (1,4) gray prediction equation:

$$\hat{x}_1^{(1)}(k+1) = \Big\{100 - \Big[2.95898 \times x_2^{(0)}(k+1) - 1.50027 \times x_3^{(0)}(k+1) + 1.59653 \times x_4^{(0)}(k+1)\Big] \big/ 0.24502\Big\} e^{-0.24502k} + \Big[2.95898 \times x_2^{(1)}(k+1) - 1.50027 \times x_3^{(1)}(k+1) + 1.59653 \times x_4^{(1)}(k+1)\Big] \big/ 0.24502$$

The model calculates the analog value regressive reduction, then calculate residuals $e(k)$, total system error $E = \frac{1}{n}\sum_{i=1}^{n} e(i)$ .If the total error E does not meet the system accuracy in claim 10^{-5} ,the use of residual e establish

GM (1,1) model, modified the original model, until the system accuracy to meet the requirement. The average error of the model is 0.00741,prediction results are shown in Table 1.

Table 1 prediction results

well number	actual quality	predict quality	relative error	well number	actual quality	predict quality	relative error
N 1-311-P29	80	78.33804	0.020775	N 1-312-P14	100	99.79588	0.002041
N 1-311-P36	70	67.17232	0.040395	N 1-63-P260	70	73.32995	0.009572
N 1-311-P37	50	35.73179	0.285364	N 1-6-P243	70	65.93600	0.058057
N 1-311-P57	70	69.52221	0.006826	N 1-6-P247	70	53.27376	0.667518
N 1-311-biasP41	70	18.15095	0.740701	N 1-6-P254	70	69.26048	0.010565

By training the model results and the predicted results can be seen, the paper establishes the GM (1,4) model to predict the quality of cementing can reflect the characteristics of the actual cementing quality system. Accuracy of the model to meet the requirements, the prediction accuracy rate can reach 70%, this model can be used to simulate oilfield cementing quality system, the actual construction of the oilfield cementing have some significance.

CONCLUSION

There are many factors that affect the quality of cementing, and between these factors have contact with each other, it is difficult to establish the mathematical model between them. Gray system can use little data, extracting valuable information to achieve operational behavior of the system, the correct description of the evolution. This paper selects nine major factors cementing quality from a number of factors, and use of principal component analysis method to reduce the dimension, lower nine factors to three, reducing the amount of calculation and simplifies the model. The paper establishes the GM (1,4) model through a new variable to predict the quality of cementing, higher model precision, better prediction, the actual construction of the oilfield cementing has some significance.

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