Analysis of Coalbed Methane Reservoir Properties Based on Grey Correlation Prediction

Jianjun Wu¹, Lingpeng Meng¹, Bing Li¹, Xiaoya Chen²*, and Han Lu²

¹Engineering technology research institute of petrochina coal-bed methane co. LTD, Shaxi 710082, China
²School of Sciences, Southwest Petroleum University, Chengdu 610500, China

*Corresponding author e-mail: danliswu@sina.com

Abstract. According to the grey system theory, this paper selects some logging parameters that are sensitive to the fluid properties of coalbed methane reservoirs, predicts the fluid properties of unknown coalbed methane reservoirs by using grey correlation analysis method, determines the correlation factor and correlation degree between the evaluation index of fluid properties of coalbed methane reservoirs and actual data, and quantitatively describes the categories of unknown fluid properties according to the correlation degree. By analyzing various logging data and comparing the identification result with the gas test conclusion, the accuracy rate is as high as 95%, which can accurately judge the gas-bearing property of the reservoir. This shows that the grey correlation prediction is feasible, with high accuracy and ideal effect.

Keywords: Reservoir Properties, Grey System Theory, Grey Relational Analysis Method, Relevance Degree

1. Introduction

For coalbed methane reservoirs, there are not only a lot of known information, but also a lot of unknown and unascertained information. If you want to know its nature, you need to analyze it.

As for the nature of coalbed methane reservoirs, the most commonly used method so far is the expert evaluation method. The expert evaluation method is easily influenced by the authority and opinions of the majority of people, and is not willing to publicly revise some psychological factors of personal opinions, which hinders the conclusion of reasonable conclusions. Using grey correlation analysis method to identify gas layer and gas-water layer is to regard coalbed methane reservoir as a grey system, which includes some known information and unknown information.

Grey correlation analysis is to quantitatively describe the relationship or development trend between variables according to the correlation degree between variables. If the correlation degree between the comparison sequence and the reference sequence is large, the relationship between the two is considered to be close, while if the correlation degree is small, the relationship between the two is distant. This is used as the basis to judge the correlation.
2. Evaluation Procedure

2.1. Identify the Reference Series and Reference Series
When receiving the paper, we assume that the corresponding authors grant us the copyright to use the paper for the book or journal in question. Should authors use tables or figures from other Publications, they must ask the corresponding publishers to grant them the right to publish this material in their paper. Based on gas bearing evaluation of coalbed methane reservoir, a reference series was constructed \( X_0 = \{x_0(1), x_0(2), ..., x_0(k), \ldots\} \) The samples to be identified constitute a comparison series \( X_i = \{x_i(1), x_i(2), ..., x_i(k), \ldots\} \) The standard model library of fluid properties was obtained by analyzing the confirmed gas layers, differential gas layers and dense layers [1].

2.2. Raw Sequence Data Preprocessing
Due to the different physical meanings of each logging parameter, the dimensions and quantities of each logging value vary greatly. In order to eliminate the influence of data dimensions on the prediction results, the original data need to be preprocessed [2]. The calculation formula is
\[
x_{ij}' = (x_{ij} - x_{j\text{max}}) / (x_{j\text{max}} - x_{j\text{min}})
\]

(1)

2.3. Find the Absolute Value of the Difference Between the Reference Sequence and the Comparison Sequence
Calculate the absolute value of the difference between the reference sequence and the comparison sequence at each point \( \Delta_j(k) \) [3], mean
\[
\Delta_j(k) = |x_j(k) - x_0(k)|
\]

(2)

2.4. Find the Correlation Coefficient.
\[
r(x_0(k), x_i(k)) = \frac{\min_k \Delta_j(k) + \alpha \max_k \Delta_j(k)}{\Delta_j(k) + \alpha \max_k \Delta_j(k)}
\]

(3)

Type in the \( \alpha \)-identification coefficient, ordinary \( \alpha \) get 0.5 [4].

2.5. Strives for the Correlation
\[
r(x_0, x_i) = \frac{1}{n} \sum_{k=1}^{n} r(x_0(k), x_i(k))
\]

(4)

2.6. The Sequence of Association is Determined by the Maximum Membership Principle
The maximum membership principle is adopted after the correlation degree of gas bearing evaluation is calculated \( P_{\text{max}} = \max_i \{P_i\} \) As a conclusion of gas bearing evaluation and prediction of coalbed methane reservoir [5].

3. The Grey Relational Model Determines the Final Parameters of Fluid Identification
According to the study on the gas bearing degree of the coalbed gas reservoir in the block [6], the gas bearing property of the coalbed gas reservoir can be divided into three types: gas, differential gas and tight gas [7]. It is a pattern recognition problem to extract the logging parameters that are sensitive to the gas bearing property of the coalbed gas reservoir to determine which type of gas bearing property the coalbed gas reservoir belongs to. Extract deep resistivity, acoustic time difference, density, natural
gamma, compensated neutron, porosity, porosity difference [8]. The 10 parameters, porosity ratio, permeability and gas saturation, are used as characteristic parameters to identify fluid properties. The grey relation of equal weight is used to judge the most sensitive parameter to the gas bearing property of coalbed gas reservoir, and then the weight method is used to identify the property of coalbed gas reservoir.

The grey correlation model is used to analyze the gas bearing property of 36 groups of coal-bed gas reservoirs confirmed by gas test in shaanxi province. The fluid property of coal-bed gas reservoirs is taken as the reference sequence, and 10 logging characteristic parameters are taken as the comparison sequence. The correlation degree of each characteristic parameter and fluid property is shown in table 1-1.

**Table 1-1.** Grey correlation degree between characteristic parameters and fluid properties.

| Logging parameters | The resistivity correlation | Acoustic time | The density of | Natural gamma ray | Compensated neutron |
|--------------------|-----------------------------|---------------|----------------|-------------------|---------------------|
|                    | 0.497                       | 0.710         | 0.583          | 0.592             | 0.579               |
| Logging parameters | porosity correlation         | Porosity difference | Porosity ratio | hole              | Gas saturation      |
|                    | 0.626                       | 0.671         | 0.596          | 0.672             | 0.819               |

It can be seen that the five most sensitive gas bearing parameters of coalbed methane reservoir. The five parameters with the highest correlation of fluid properties are: acoustic time difference, porosity, porosity difference, gas saturation and permeability. The five parameters with the largest properties related to fluid properties are used as the final parameters to identify fluid properties, and the weight coefficient is determined by correlation coefficient method, whose formula is

$$w_i = p_i / \sum_{i=1}^{n} p_i$$

(5)

Type in the $w_i$—Weight of each characteristic parameter; $p_i$ —Grey correlation degree between each characteristic parameter and the property of coalbed gas reservoir [9, 10].

After the weights of each parameter are determined, the weighted grey relational model is used to predict the fluid properties. The weights in the weighted grey relational model are determined by the grey relational analysis of average weight. The weights of the five parameters are shown in table 1-2.

**Table 1-2.** Weights of characteristic parameters.

| Logging parameters | Acoustic time | porosity | porosity difference | permeab | Gas saturation |
|--------------------|---------------|----------|---------------------|---------|----------------|
| Weights            | 0.203         | 0.179    | 0.192               | 0.192   | 0.234          |

4. The Weighted Grey Relational Model is Used to Identify Fluid Properties

In the confirmed strata, the average logging parameters of 10 groups of gas reservoir samples, 5 groups of differential gas reservoir samples and 5 groups of tight layer samples were selected to establish a standard model library of CBM reservoir fluid properties (table 1-3). In order to analyze the correlation degree between the CBM reservoir to be identified and the CBM reservoir samples in the standard model reservoir, the CBM reservoir samples in the standard model reservoir to be identified were taken as the reference sequence and the CBM reservoir samples to be identified as the comparison sequence[11].
Table 1-3. Standard model reservoir of CBM reservoir fluid properties.

| Fluid type            | Logging parameters |          |          |          |          |
|-----------------------|--------------------|----------|----------|----------|----------|
|                       | Acoustic time      | porosity | porosity difference | permeability | Gas saturation |
| gas                   | 234.89             | 8.88     | 1.14     | 0.029    | 61.29    |
| Bad atmosphere        | 216.81             | 5.85     | -2.46    | 0.021    | 33.48    |
| Dense layer           | 199.74             | 3.68     | -2.99    | 0.017    | 11.14    |

According to the principle of maximum membership degree in grey correlation, the fluid type of coalbed methane reservoir can be identified. Coalbed methane reservoir laminar liquid identification steps: first select 10 kinds of hydrocarbon content related parameters, and second use are weighted grey correlation model to select the highest correlation coefficient of 5 kinds of parameters to 5 classes give weight and the establishment of the laminar liquid storage standard model library with weighted grey correlation model, the final judgment to identify the laminar liquid storage.

In order to verify the effectiveness of the method, 20 layers to be identified in Shaanxi were identified, and their correlation degrees with three fluid types were shown in Table 1-4

Table 1-4. Correlation between the layers to be identified and three fluid types.

| Well no.    | Horizon   | Gas correlation | Difference gas correlation degree | Degree of correlation of dense layer |
|-------------|-----------|-----------------|-----------------------------------|-------------------------------------|
| 4-7 Well    | Box 8     | 0.846           | 0.474                             | 0.460                               |
|             | Box 4     | 0.848           | 0.555                             | 0.510                               |
| 4-9 to 2    | Box 8     | 0.545           | 0.728                             | 0.624                               |
|             | Mountain 23| 0.693           | 0.442                             | 0.432                               |
| 5-4 to 6    | Mountain 21| 0.711           | 0.651                             | 0.632                               |
|             | Majiagou  | 0.457           | 0.716                             | 0.746                               |
| 7-6 Well    | Taiyuan   | 0.736           | 0.502                             | 0.502                               |

The recognition results were compared with the gas test results (Table 1-5).
Table 1-5. Grey correlation degree prediction results of gas bearing of coalbed methane reservoirs.

| Well no. | Horizon | Acoustic time (μs/m) | porosity (%) | Three pore difference (%) | permeability (mD) | Gas saturation (%) | Predict type | Maximum correlation | Testing results |
|----------|---------|----------------------|--------------|---------------------------|------------------|-------------------|--------------|---------------------|-----------------|
| 4-7      | Box 8   | 240.52               | 12.99        | 2.645                     | 0.033            | 62.41             | Gas          | 0.846               | Gas             |
|          | Box 4   | 231.58               | 9.68         | 3.651                     | 0.028            | 59.12             | Gas          | 0.848               | Gas             |
| 4-9 to 2 | Box 8   | 224.91               | 7.12         | -12.760                   | 0.019            | 37.65             | Bad atmosph  | 0.728               | Bad atmosph     |
|          | Mounta in 23 | 244.45       | 9.6      | 8.744                     | 0.034            | 69.33             | Gas          | 0.693               | Gas             |
| 5-4 to 6 | Mounta in 21 | 223.3        | 9.86      | 1.646                     | 0.017            | 50.01             | Gas          | 0.711               | Gas             |
| 7-6      | Majia gou | 205.71         | 4.24       | -8.136                    | 0.012            | 33.39             | Dense layer  | 0.746               | Bad atmosph     |
|          | Taiyuan | 253.85               | 11.41       | -3.492                    | 0.037            | 64.26             | Gas          | 0.736               | Gas             |

The identification of 19 groups of coal bed methane reservoirs to be identified is correct, and the identification of 1 group of coal bed methane reservoirs to be identified is wrong. The discriminating accuracy is up to 95%. The application of grey correlation method in the identification of coalbed methane reservoir fluid is feasible.

5. Conclusion

Qualitative identification of coalbed methane reservoir hydrocarbon content, the method of convenient for simple and intuitive judgment of coalbed methane reservoir hydrocarbon content, improving the efficiency of the application of quantitative identification of coalbed methane reservoir hydrocarbon content, the method of the analysis of various logging data, can be more accurate judgment of coalbed methane reservoir hydrocarbon content, compared with the three porosity difference ratio method, grey correlation method, higher accuracy, the effect is more ideal.

Acknowledgments

This research was funded by the National Science and technology Major Project of China (No. 2016ZX05066-003, 2016ZX05042-003).

References

[1] Ni Jian, Chen Su, Wang Bin, Zhou Dan, Chen Jieyao. Grey Correlation Analysis of Long-term Settlement of Shield Tunnels in Subway [J]. Forest Engineering, 2018,34(01):71-74.
[2] Yang Zhen, Geng Xiuli. Proposal Recommendation Based on Hybrid Algorithm of Grey Relational Prediction and Trust Cloud [J/OL]. Computer Integrated Manufacturing System: 1-14 [2019-11-27].
   HTTP://kns.cnki.net/KCMS/Detail/11.5946.TP.20180927.1410.003.html.
[3] Lu hui. Implicit correlation prediction model of complex systems based on grey correlation analysis [J]. Journal of jiamusi university (natural science edition),2016,34(01):110-113.
[4] Zhu chao, ju jian-bo, wang peng, hu sheng-lin. Anti-submarine patrol aircraft search decision
based on grey correlation decision and combination weighting method [J]. Command and control & simulation, 2017, 39(02): 10-14.

[5] Du hongcheng, yan yujing. Determination of indispensable weights in comprehensive evaluation [J]. Heilongjiang science and technology information, 2009(03): 58+211.

[6] Zhengguang Zhang, Yong Qin, Zhaobiao Yang, Jun Jin, Congcong Wu. Fluid energy characteristics and development potential of coalbed methane reservoirs with different synclines in Guizhou, China [J]. Journal of Natural Gas Science and Engineering, 2019, 71.

[7] Gao lijun, xie yinggang, pan xinzhi, pang jianlong, zhou longgang. Analysis on gas bearing and geological model of deep coal bed methane development in linxing [J]. Acta coal sinica, 2008, 43(06): 1634-1640.

[8] Sun yunchuan. Comprehensive logging evaluation method for coal seam gas content [J]. Energy technology and management, 2019, 44(03): 148-150.

[9] Guo yu. Overview of weight determination methods [J]. Rural economy and science and technology, 2008, 29(08): 252-253.

[10] Gao wei, gao yi. Analysis of influencing factors of air traffic controllers' workload based on weighted grey correlation [J].

[11] Geng hong, Yang shenglin, Chen jingjie. Energy efficiency evaluation of air transport enterprises based on grey weighted correlation [J]. Machine tool & hydraulics, 2008, 46(12): 58-63.