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Quantitative Evaluation of Complex Carbonate Reservoir based on Fuzzy Clustering Analysis

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Abstract

There are many factors affecting reservoir properties, and these factors often have intricate correlations. In view of these characteristics, taking the carbonate reservoir of the second member of Jialingjiang Formation in Moxi gas field in central Sichuan Basin as an example, the porosity, permeability, water saturation, displacement pressure, average pore throat radius, reservoir effective thickness, permeability variation coefficient, permeability breakthrough coefficient and permeability ratio are selected as reservoir evaluation factors, and fuzzy clustering analysis method is used to evaluate reservoir quality. The evaluation results are in good agreement with the actual productivity of gas field.

Keywords

Carbonate Rock; Complex Reservoir; Quantitative Evaluation; Fuzzy Clustering; Moxi Gas Field.

1. Introduction

The complex carbonate reservoir is controlled by the comprehensive effect of sedimentation, diagenesis and tectonism, which is characterized by different reservoir space types, micro pore throat structure, physical property distribution and significant heterogeneity. Quantitative evaluation of complex carbonate reservoirs is helpful to reflect their fluid storage and seepage capacity, predict high-yield and low-yield areas, and make a reasonable development plan. At present, there are many methods for quantitative evaluation of complex carbonate reservoirs, such as weighted average method, Fisher multi-parameter discriminant method, principal component analysis, fuzzy comprehensive evaluation [1-6]. In this paper, taking the complex carbonate reservoir of the second member of Jialingjiang Formation in Moxi gas field as an example, the fuzzy clustering analysis method is used to quantitatively evaluate the reservoir quality, and the results are tested in combination with the actual productivity.

2. Fuzzy Clustering Analysis Method for Quantitative Evaluation of Complex Carbonate Reservoirs

There are some shortcomings in directly starting from the concept of complex carbonate reservoirs or using factor analysis to evaluate complex carbonate reservoirs [1-6]. When the fuzzy clustering method is used for quantitative evaluation of complex carbonate reservoirs, the samples are regarded as points in Euclidean (Mahalanobis) space and classified by sample membership. This method avoids the complexity of the multi-step method and prevents the transmission of mistake [7]. In the case of certain parameters, there is no impact of human factors, inter-class characteristics obvious.

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Let Q be a sample matrix for the p-dimensional population U, and the sample length is l (known). Since the data dimensions of the p features (known) of the sample are different, it is normalized first. The original data translation standard deviation transformation, transformation formula is as follows:

$$r_{ij} = \frac{x_{ij}-x_{imin}}{x_{imax}-x_{imin}} \tag{1}$$

$$r_{ij} = \frac{x_{ijmax}-x_{ij}}{x_{imax}-x_{imin}} \tag{2}$$

In (1) and (2), rij is the normalized eigenvalue; xij is the known sample characteristic value; max and min are the maximum and minimum values of the ith characteristic obtained from l samples, respectively. Formula (1) For positively correlated indicators, Formula(2) Indicators for negative correlation.

The normalized sample matrix Q is transformed into fuzzy characteristic matrix of elements in [0, 1] Interval.

$$R= (rij)m\times n \tag{3}$$

Where, i = 1, 2..., m; j = 1, 2,..., n ; $0 \le rij \le 1$.

The sample Q with a capacity of l is divided into q classes, and each class of the sample has a central point, called the cluster center. The matrix describing the cluster center (fuzzy equivalent matrix) is expressed as:

$$\psi = (\psi ih)m\times q. \tag{4}$$

Where, i = 1,2..., m; h = 1, 2,..., q ; $0 \le \psi ih \le 1$, ψih represents the clustering center value of the h-th cluster center feature i, which is determined by multiple iterations according to the given number of categories in the clustering process.

Finally, the elements of fuzzy equivalence relation matrix ψih are transformed to represent the similarity between classified objects. The elements of ψih are arranged from large to small as the prescribed level value λ ($0 \le \lambda \le 1$).

$$C\psi_{ih}= \begin{cases} 0\ , & \psi_{ih}\ge \lambda \\ 1\ , & \psi_{ih}\ge \lambda \end{cases} \tag{5}$$

Where, C represents a judgment matrix, dimensionless.

Using the level cut set of λ of the obtained fuzzy equivalence relation to classify, the classification is from coarse to fine. If the minimum value of the element in the fuzzy equivalence relation matrix ψih is λ, it is classified into one class. Select the second minimum value for the λ value is divided into 2 class ; select the qth minimum value for the λ value is divided into q class... If λ = 1, each sample is a class. In this way, a dynamic clustering system can be formed from fine to coarse and gradually merged to complete fuzzy clustering analysis (Fig.1) to achieve the purpose of classification [8-14].

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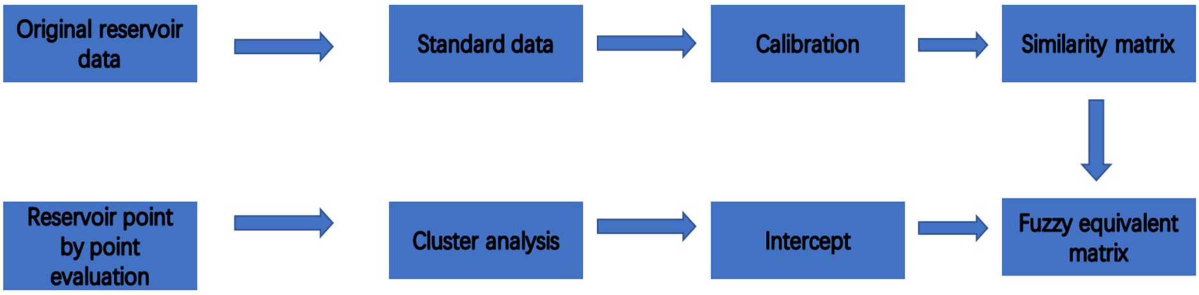

Figure 1. Quantitative evaluation process of carbonate reservoir based on fuzzy clustering analysis

3. Example Analysis

3.1 Overview of the Study Area

Moxi gas field is located in the southern part of the middle oblique flat structural belt of central Sichuan paleo-uplift, Sichuan Basin. The Lower Triassic Jialingjiang Formation Member 2 marine carbonate rock is the main pay zone of the gas field, which can be further divided into Jia2 1, Jia 2 2 and Jia 23 sub-members. Jia2 2 sub-member can be subdivided into three layers: Jia 2 2 A, Jia 2 2 B and Jia2 2 C, which have the typical characteristics of facies-controlled complex carbonate reservoirs [4]. In the vertical direction, the lithologic characteristics, reservoir space types, microscopic pore throat structure and physical property distribution of each set of reservoirs are different, which constitutes a number of sets of reservoir combinations with different genetic types. In the horizontal direction, it is mostly lenticular distribution, and the local performance is layered reservoir with significant heterogeneity. At the same time, the development and distribution of reservoirs are controlled by sedimentary cycles and sedimentary microfacies.

3.2 Selection of Fuzzy Clustering Parameters

The parameters reflecting reservoir physical property, pore throat structure, facies controlling factors and heterogeneity are used to characterize the superposition characteristics of reservoir sedimentary factors and diagenetic factors of the samples. For each small layer of carbonate reservoir in the second member of Jialingjiang Formation, l = 2017, p = 8, q = 5. This clustering is based on the average value of sample points of various parameters of carbonate reservoir in each small layer. (It should be noted that in order to improve the clustering accuracy, invalid reservoir sample points such as porosity $\Phi \leq 0.01$ % and permeability $K \leq 0.001 \times 10\text{-}3\mu m2$ are eliminated). the parameters of fuzzy clustering are porosity (Φ), permeability (K), displacement pressure (pd), average pore throat radius (R50), effective thickness (H), permeability breakthrough coefficient (TK), permeability coefficient of variation (VK) and permeability ratio (JK).

Among them, porosity (Φ) and permeability (K) reflect the physical properties of reservoir rock ; displacement pressure (pd) and average pore throat radius (R50) reflect the microscopic pore structure characteristics of rock ; effective thickness (H) reflects the effective reservoir thickness and has an important influence on oil and gas productivity. The permeability breakthrough coefficient (TK), permeability variation coefficient (VK) and permeability ratio (JK) reflect the heterogeneity of reservoir [1-2].

3.3 Fuzzy Clustering Results and Type Characteristics

The above 8 parameters are selected for fuzzy clustering analysis of each sublayer in Jia 2 Member. The results are shown in Table 1.

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Table 1. Fuzzy clustering results of the second member of Jialingjiang Formation in Moxi structure

Type	Reservoir evaluation	Φ /%	K /10^{-3} μm^2	p_d / MPa	R_{50} /μm	H /m	V_K	T_K	J_K
I	Good	16.91	2.12	3.99	0.870	8.99	0.38	1.89	0.47
		12.66	1.44	2.71	0.610	7.41	0.31	1.53	0.36
		10.13	1.02	0.92	0.530	7.12	0.12	0.17	0.19
II	Be relatively good	9.69	0.97	7.85	0.490	6.73	0.79	2.91	0.94
		8.41	0.66	5.73	0.360	5.92	0.55	2.42	0.73
		8.12	0.54	4.37	0.210	4.11	0.43	2.02	0.53
III$_1$	General	7.83	0.43	11.62	0.190	3.88	1.19	3.98	1.87
		5.95	0.31	10.44	0.090	2.74	0.93	3.81	1.38
		5.26	0.22	8.93	0.050	1.12	0.85	3.11	1.09
III$_2$	Be relatively poor	4.93	0.19	17.51	0.042	0.91	1.94	5.64	2.52
		2.94	0.16	15.36	0.024	0.67	1.04	4.47	2.05
		2.26	0.13	13.33	0.011	0.55	0.92	4.03	1.89
IV	Poor	2.03	0.08	21.61	0.030	0.31	2.13	7.64	3.52
		1.74	0.05	19.56	0.006	0.27	1.74	6.91	3.05
		0.26	0.02	18.91	0.001	0.17	1.22	6.27	2.67

(Note: JK is a logarithmic value; the three values of each evaluation parameter are maximum, average and minimum from top to bottom).

It can be seen from the table that: 1(as the reservoir quality changes from poor to good, Φ, K, R50 and H change from low to high, and Pd, TK, VK and JK change from high to low. 2 (Class I reservoir is of good quality, with high porosity and permeability. The porosity is above 10.13% and the permeability is above 1.02×1 0-3 μm2; The pore throat structure is good, the drainage pressure is less than 3.99 MPa, and the average pore throat radius areaches 0.61 μ m; Large effective thickness; Heterogeneity is weak. Class II reservoir is relatively good quality, with average porosity of 8.41% and average permeability of 0.66×10-3 μm2.The pore throat structure is good, the displacement pressure is 4.37 ~ 7.85 MPa, the average pore throat radius is 0.36 μm; the effective thickness is thick, with an average of 5.92 m. The heterogeneity is weak. The quality of type III1 reservoir is general, the average porosity is 5.95 %, and the average permeability is 0.31×10-3 μm2. The pore throat structure is general, and the average pore throat radius is 0.09 μm when the displacement pressure is 8.93 ~ 11.62 MPa. The effective thickness is thin, averaging 2.74 m; the heterogeneity is strong. Type III2 reservoir is relatively poor reservoir with average porosity of 2.94 % and average permeability of 0.16×10-3 μm2 ; pore throat structure is poor, displacement pressure is 13.33 ~ 17.51 MPa, average pore throat radius is 0.024 μm; effective thickness thin, average 0.67 m; strong heterogeneity. Class IV reservoirs are poor reservoirs with poor physical properties. The average water saturation is 73.43 %. The pore throat structure is poor, the effective thickness is very thin, and the heterogeneity is very strong. 3(good reservoir corresponds to good reservoir properties, good pore throat structure, thick effective thickness and weak heterogeneity. Type I, II and III1 reservoirs are recoverable reservoirs, while type III2 and IV poor reservoirs are difficult to use under the condition of combined injection and production.

3.4 Reservoir Quantitative Evaluation Result Test

Type I and II reservoirs are distributed in favorable or relatively favorable reservoir facies belts of beach-core microfacies and beach-margin microfacies; Type III1 reservoirs are distributed in general reservoir facies belts such as inter-beach sea; Type III2 and IV non-reservoirs are distributed in unfavorable reservoir facies belts such as lagoon areas. The liquid production capacity of type I and II reservoirs is high, the liquid and gas production capacity of type III1 reservoir is general, and the liquid production capacity of type III2 and IV poor or non-reservoir is almost zero.

The purpose of quantitative reservoir evaluation is to classify the quality of oil and gas reservoirs and predict high and low production areas. Because most of the small layers in the second member of Jialingjiang formation in the study area are combined injection and production, it is not easy to carry out production splitting. Therefore, the quantitative evaluation results of reservoirs are tested by

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combining the productivity data of single well production layer and the reservoir capacity information of small layers.

Figure 2 shows the gas production capacity histogram of 8 wells in the Jia 2 Member of the study area. It can be seen from the figure that the daily gas production of Well M5 and Well M13 is the highest, reaching 22.94×104 m3 and 26.67×104 m3 respectively, followed by Well M24 and Well M154, which are 13.62×104 m3 and 9.43×104 m3 respectively. The reservoir quality of M5 well, M13 well, M24 well and M154 well is good or better, which belongs to class I, II, III1 reservoir, and its productivity is relatively high. The productivity of M46 well, M149 well, M206 well and M208 well is relatively low. The quantitative evaluation results of the reservoirs in the Jia2 2 B layer of these four wells are III2 poor reservoirs and IV poor reservoirs. Therefore, the above reservoir evaluation results are in good agreement with single well productivity, which can reflect the quality of reservoir.

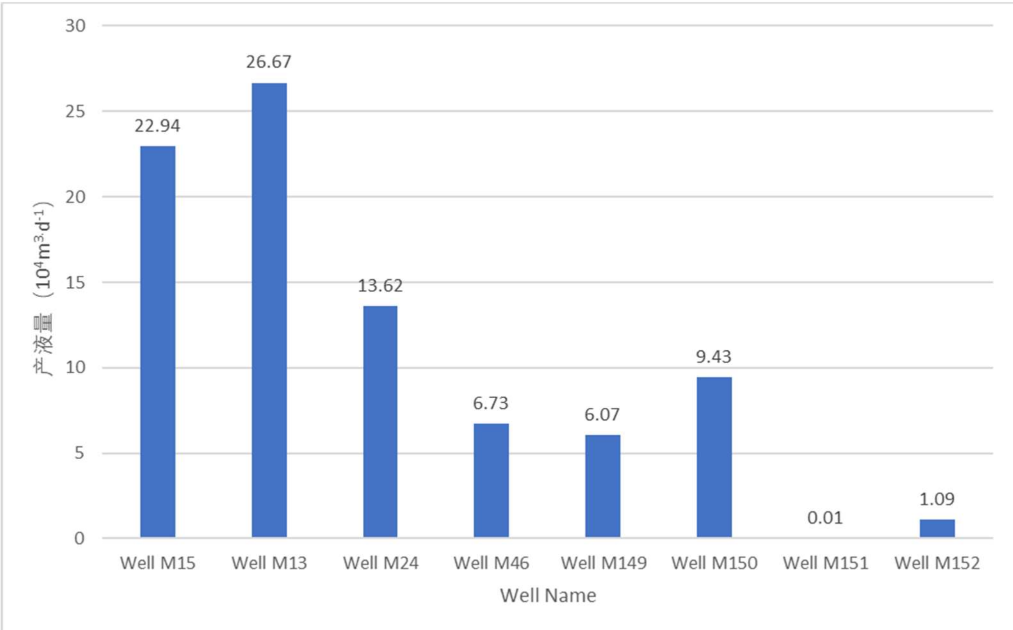

Figure 2. Productivity of some wells in Jia 2 member of Moxi area

4. Conclusion

(1) There are many quantitative evaluation methods for carbonate reservoirs, but they have limitations to varying degrees. Fuzzy clustering technology can reduce the error conduction of multi-step method, which has clear thinking and fast operation. It is an ideal method for quantitative evaluation of complex carbonate reservoirs.

(2) The fuzzy clustering quantitative evaluation results of complex carbonate reservoir quality are consistent with the reservoir productivity, indicating that the carbonate reservoir quality classified by this method can better reflect the objective reservoir performance characteristics. The classification and evaluation of reservoirs can be used as the basis for the adjustment of oil and gas field development measures and the rational management of reservoirs.

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