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Application of Fuzzy Mathematical Evaluation Method in Classification and Evaluation of Condensate Gas Reservoir

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ABSTRACT

In order to comprehensively reflect the influence of seven parameters, such as permeability, porosity, reserves abundance, reservoir depth, condensate oil content, edge and bottom water energy, and development mode, on the development effect of condensate gas reservoirs, fuzzy mathematics method was applied to classify and evaluate typical condensate gas reservoirs in China. The classification of condensate gas reservoirs considering the content of condensate oil and other single factors cannot objectively and accurately characterize the quality of condensate gas reservoirs. By selecting the relevant parameters of 18 condensate gas reservoirs in China, the comprehensive evaluation value B is obtained by using fuzzy mathematical evaluation method on the basis of single factor evaluation, and then the condensate gas reservoirs are divided into four categories: B 0.6, which is a type of condensate gas reservoir; 0.5 B < 0.6 is a type two condensate gas reservoir; 0.4 B < 0.5, third type of condensate gas reservoir; B < 0.4 is the fourth type of condensate gas reservoirs. The practice shows that the factors considered in this classification and evaluation method are more comprehensive and the evaluation results are more scientific, so the evaluation results can lay a theoretical foundation for the evaluation of the development effect of condensate gas reservoirs in China.

INTRODUCTION

Condensate gas reservoir is an important natural gas resource in China, which is widely distributed in Bohai bay, Tarim basin, Tuha basin and east and south coastal shelf area. However, they (such as Yaha, Yakla-Dalawaba, Mahe, Kelameili, Hutubi and other condensate gas reservoirs) have different reservoir types, condensate oil content and water activity (Behmanesh et al. 2017). The geological and engineering production conditions of condensate gas reservoirs differ greatly in the development effect. At present, the types of condensate gas reservoirs in China are mainly classified according to the content of condensate oil. In addition to the content of condensate oil, there are many factors affecting the development effect of condensate gas reservoirs (Ming et al. 2017). Under ideal conditions, the factors affecting the development of condensate gas reservoirs are mainly divided into geological conditions and production conditions. Among them, geological conditions mainly include original pressure, reservoir permeability, porosity, gas saturation, effective thickness, fracture development, edge and bottom water energy, condensate oil content, etc. (Liu 2017). Production condition basically has development means, abandon yield to wait. Therefore, the classification with condensate oil content as the standard will bring many problems to the determination of condensate gas development plan and development index (Wang et al. 2017).

In recent years, although many scholars have carried out a large number of studies on the evaluation and prediction of condensate gas reservoir development indicators by using reservoir engineering method and numerical simulation method respectively, they have not comprehensively considered the type of condensate gas reservoir under multiple influencing factors, so they cannot scientifically evaluate the development of condensate gas reservoir. The classification results of condensate gas reservoirs are different according to different goals and development standards. In the process of classification, it is necessary to seek a standard that can better reflect the geological characteristics of the actual gas reservoir, so as to have guiding significance in the actual production.

In order to better guide the development of condensate gas reservoirs, it is necessary to establish a set of classification and evaluation methods for condensate gas reservoirs under the consideration of multiple factors (such as gas reservoir geology, production conditions, etc.). Therefore, on the basis of analysing the influencing factors of condensate gas reservoir development indexes, combining with a large number of actual data of condensate gas reservoirs, this paper makes a more scientific classification and evaluation of typical condensate gas reservoirs in China by using engineering fuzzy mathematics method.

PAST RESEARCH

Based on the Bohai sea gas reservoir B (high condensate) test results, considering the reservoir pressure sensitive effect and the test in the process of working liquid and gas condensate liquid, the effect of improved binomial equation were deduced, Bohai sea abnormal high pressure condensate gas reservoir capacity evaluation model is established, and is applied to conduct research on the Bohai sea B gas reservoir (Dongdong et al. 2018). Based on the pseudo-single-phase seepage equation and the oil-gas two-phase seepage equation, Jialiang et al. (2018) established the productivity evaluation method of pseudo-single-phase stable point and gas-liquid two-phase stable point after the flow of gas wells reached the quasi-stable stage. Through classified evaluation, a research determined that there were two types of oil-ring condensate gas reservoirs in this area. Based on numerical simulation, they demonstrated the development process, development mode, pressure maintenance level and gas well operation timing, and proposed appropriate development countermeasures (Songjiang et al. 2018). In the process of cyclic gas injection displacement of condensate gas reservoirs, a study found that the injected dry gas was easily injected along the high-permeability channel or natural fractures due to the influence of reservoir heterogeneity, which affected the development effect of condensate gas reservoirs (Yongchang et al. 2017, Kang et al. 2017).

RESEARCH METHODS

The development index of condensate gas reservoir is affected by many factors. How to unify these factors effectively and make scientific, objective and comprehensive evaluation on the classification of condensate gas reservoirs is the key to evaluate the development effect of condensate gas reservoirs. Based on the analysis of the main factors affecting the development indexes of condensate gas reservoirs, the classification of condensate gas reservoirs is quantitatively analysed by using the method of fuzzy comprehensive evaluation, which provides a theoretical basis for the comparison and judgment of the development indexes.

Quantification of Qualitative Indicators

In the multi-attribute decision making problem, the attribute index of the decision object usually has qualitative and quantitative two different representations. In order to facilitate the necessary mathematical processing of the attribute index, the Bipolar Scaling method proposed by Mac Crimmon is generally adopted to convert the qualitative index into the quantitative index, and the conversion mode is shown in Fig. 1.

Normalization of Decision Matrix

Because the numerical units of different attribute indexes are usually different, if the values of attribute indexes are not normalized, there will be no comparability between attributes. The parameters of attribute index can be normalized by proportional transformation method. The proportional transformation method adopts different conversion methods for different types of attributes. For the attribute index of income, its conversion formula is:

$$x_{ij} = \frac{x_{ij}}{x_{j,\max}} \quad \ldots(1)$$

$$x'_{ij} = \frac{x_{ij} - x_{j,\min}}{x_{j,\max} - x_{j,\min}} \quad \ldots(2)$$

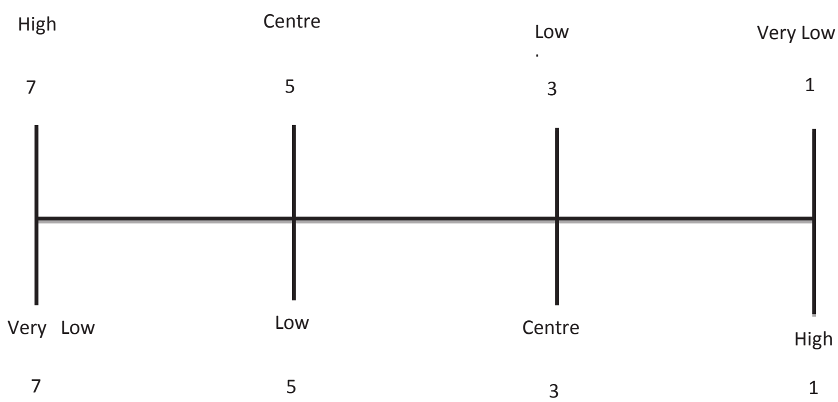

Fig. 1: Bipolar proportional method for the conversion of qualitative index to quantitative index.

For expenditure attribute indicators, the corresponding conversion formula is:

$$x'_{ij} = \frac{x_{j,\min}}{x_{ij}} \quad \ldots(3)$$

$$x'_{ij} = \frac{x_{j,\max} - x_{ij}}{x_{j,\max} - x_{j,\min}} \quad \ldots(4)$$

In formula (1) ~ (4), xij is the j^{th} target data obtained in the i^{th} series.

Fuzzy Comprehensive Evaluation

Fuzzy comprehensive evaluation method is a method based on fuzzy transformation principle, maximum membership principle analysis and fuzzy evaluation. It is also a quantitative and qualitative evaluation method with fuzzy reasoning as the main method. It is according to the requirements of the evaluation problem, each object to judge, judge the size of the corresponding index, and sort, so as to classify the object or sentenced the best. Definition of fuzzy comprehensive evaluation method: Let U and V be two non-empty sets. If there is A corresponding rule T for the fuzzy power set P(U) to the fuzzy power set P(V) of U, then T is the fuzzy transformation from U to V, denoted as:

$$\begin{aligned} &T: P(U) \rightarrow P(V) \\ &A \rightarrow T(A) = B \in P(V) \end{aligned} \quad \ldots(5)$$

Due to the different roles of various factors in the comprehensive evaluation, a fuzzy set A= a1, a2, a3... + an = 1, A is called the weight vector of the comprehensive evaluation (referred to as the weight), and a_i represents the weight of factor x_i in the comprehensive evaluation. For the given weight A, the comprehensive evaluation is a fuzzy transformation from the factor set U to the comment set V:

$$T_f : A \rightarrow B = T_f(A) = A \otimes R \quad \ldots(6)$$

Let the domain be U, A1, A2... An is n fuzzy sets of U, for x_0 in U, if

$$\mu_{Ak}(x_0) = \max\{\mu_{A1}(x_0), \mu_{A2}(x_0), \ldots \mu_{An}(x_0)\} \quad \ldots(7)$$

Hence, we can say that x_0 is relative to Ak.

Fuzzy comprehensive evaluation method adopts the most basic idea in fuzzy mathematics, i.e. fuzzy set theory. Classic collection (general collection) is a research GUI absolutely belonging to the concept of things, and in the fuzzy set is the concept of relative research GUI belonging to the fuzzy set theory, because the things of a certain variability (random), argues that the development of things are not absolute, but rather from absolute to relative to a gradual process. Relative to the number or size of a set, the degree of membership mentioned above fully proves that fuzzy comprehensive evaluation method is a qualitative to quantitative analysis method. Since fuzzy comprehensive evaluation method adopts fuzzy set theory, which is the method to study the change process of things, its result is expressed by a vector, which further indicates the biggest feature of this method: intuitive understanding of the transition change of fuzzy property of things.

Determination of Membership Function

Membership function is a function that reflects the degree to which an element belongs to a certain characteristic. In the determination of membership function, because everyone has different understanding of the characteristics, and the membership function itself has certain complexity, so it can't be evaluated or selected subjectively in the determination of membership function, but must have certain objective laws. In general, the membership function is usually determined by experience or statistics, but can be determined after evaluation by experts.

Fuzzy statistical method

In a certain kind of random problem, a lot of experiments can be done. The results of each experiment can determine whether the selected element X belongs to the fuzzy set. However, it can be found that every confirmed result is a classical set, and there is a relationship between the fuzzy sets studied. However, as the number of experiments increases, the boundary of the classical set changes all the time, and the element can be included or not included.

$$\mu_n = n(A)/n \quad \ldots(8)$$

In the formula, n (A) is the number of events A, and n is the total number of trials. In probability statistics, when the number of trials increases gradually, the result of frequency will gradually become stable, that is, the so-called probability. Therefore, when the number of experiments increases gradually, the value when the frequency of elements belonging to the set tends to be stable and can be regarded as the membership degree.

Expert determination method

The determination of membership function has a certain subjectivity. If fuzzy statistical method can be used for the research content, defield method, also known as expert determination method, can be used. It is by the authority of experts based on experience and understanding to get the corresponding value, so as to determine the membership function. Although this kind of numerical value exists certain subjectivity, but it is a kind of numerical approximation. Authoritative experts will modify with the difference of things and a lot of practical experience, and each modification is the approximation of the target with high credibility.

Comparative sorting method

For some complex or relatively fuzzy sets, the membership degree can be determined by pairwise comparison.

Make use of existing membership functions

In some practical projects, some membership functions have become stable. In addition, with the long-term practice and after a lot of modification and judgment, this membership function has reached maturity and can be the description of some objective things. Then the membership function can be directly adopted to represent the membership degree of the studied things.

Taking condensate gas reservoirs in China as an example, this paper classifies condensate gas reservoirs by fuzzy mathematics method. In this paper, 7 parameters including porosity, permeability, condensate content, energy of edge and bottom water, reserve abundance, medium depth of output and development mode were selected to participate in the evaluation.

Due to the different effects of various parameters on the development of condensate gas reservoirs, the determination principles of membership functions in the comprehensive evaluation classification are different. Generally, the higher the porosity, permeability and reserves abundance, the more favourable it is for gas reservoir development. Then its membership function is:

$$\mu = \frac{x_{ij}}{x_{j,\max}} \qquad \ldots(9)$$

There is a negative correlation between reservoir depth, condensate oil content and gas reservoir development effect, and its membership function is:

$$\mu = 1 - \frac{x_{ij}}{x_{j,\max}} \qquad \ldots(10)$$

The membership function of edge and bottom water strength is converted into a quantitative index according to Fig. 1, and the membership function of the situation of edge and bottom water is:

$$\mu = \frac{x_{ij}}{7} \qquad \ldots(11)$$

According to the development method, gas injection development can play a better pressure holding effect, so that its development effect converts to quantitative indicators as shown in Fig. 1. The development mode membership function can be obtained as follows:

$$\mu = \frac{x_{ij}}{5} \qquad \ldots(12)$$

RESULTS AND ANALYSIS

On the basis of fuzzy mathematical decision theory and the determination of the membership function of related parameters, and further combining with the parameter values of related indicators of condensate gas reservoirs in China (see Table 1), the classified evaluation values of condensate gas reservoirs can be determined.

Based on the statistical data in Table 1, the corresponding membership degree is calculated according to each membership function, and the normalized matrix can be obtained by normalization processing.

$$G = \begin{bmatrix} 0.45 & 0.44 & 0.57 & 0.41 & 0.88 & 0.53 & 0.62 & 0.49 & 0.66 & 0.58 & 0.99 & 0.56 & 0.71 & 1.00 & 0.84 & 0.74 & 0.77 & 0.32 \\ -0.22 & -0.02 & -0.21 & -0.35 & 0.64 & 0.24 & 0.20 & 0.39 & 0.70 & 0.46 & 0.84 & 0.57 & 0.55 & 0.90 & 0.94 & 0.58 & 0.69 & 0.45 \\ 0.94 & 0.86 & 0.88 & 0.83 & 0.79 & 0.62 & 0.93 & 0.88 & 0.00 & 0.10 & 0.43 & 0.60 & 0.07 & 0.44 & 0.71 & 0.69 & 0.81 & 0.88 \\ 1 & 0.43 & 0.43 & 0.43 & 0.71 & 0.71 & 0.71 & 0.43 & 0.43 & 0.43 & 0.14 & 0.43 & 0.43 & 0.14 & 0.43 & 0.43 & 0.43 & 0.43 \\ 0.27 & 0.91 & 0.18 & 0.98 & 0.43 & 0.20 & 0.33 & 0.29 & 0.18 & 0.34 & 0.14 & 0.34 & 0.30 & 0.23 & 0.75 & 0.39 & 0.89 & 0.08 \\ 0.59 & 0.71 & 0.70 & 0.70 & 0.48 & 0.81 & 0.69 & 30.62 & 0.95 & 0.99 & 0.83 & 1.00 & 0.10 & 0.85 & 0.90 & 0.90 & 0.97 & 0.72 \\ 0.2 & 0.2 & 0.2 & 0.2 & 0.2 & 0.2 & 0.2 & 0.2 & 0.2 & 1 & 1 & 0.2 & 0.2 & 0.2 & 0.2 & 0.2 & 0.2 & 0.2 \end{bmatrix}$$

Further, according to the importance of the influencing factors, the decision vectors corresponding to porosity, permeability, condensate content, edge and bottom water strength, reserves abundance, reservoir depth and development mode are determined by combining expert opinions, data and the subjective and objective judgment of the analyst:

A = [0.225 0.255 0.075 0.15 0.05 0.075 0.20]

Therefore, according to equation (6), comprehensive evaluation values of different gas reservoir classification can be obtained:

B = [0.46 0.40 0.36 0.36 0.61 0.44 0.47 0.43 0.65 0.60 0.57 0.50 0.41 0.60 0.66 0.54 0.61 0.40]

Gas reservoirs can be classified based on fuzzy comprehensive evaluation results and the maximum membership principle. The comprehensive evaluation result is <0.6, which is a type ii condensate gas reservoir. Comprehensive evaluation result value <0.5, is third kind of condensate gas reservoirs. The comprehensive evaluation result value <0.4 is fourth kind of condensate gas reservoirs. The specific classification statistics are shown in Table 2.

Table 1: Statistical table of influencing factors of development indexes of different types of condensate gas reservoirs.

The name of the gas reservoir	Porosity %	Permeability $10^{-5}\mu m^3$	Condensate content g/m^3	Edge and bottom water strength	Reserves abundance $10^8 m^3/km^3$	Reservoir in deep m	The development way
DX10	10.56	0.21	38	Nothing	0.26	3060	Failure to develop
DX14	10.33	0.83	91	Edge-bottom water	16.86	3715	Failure to develop
DX17	13.28	0.22	76	Edge-bottom water	3.35	3650	Failure to develop
DX18	9.53	0.08	107	Edge-bottom water	17.89	3645	Failure to develop
River	20.62	116	133	Weak water invasion	8.03	2480	Failure to develop
The basin 5	12.63	5.98	242	Weak water invasion	3.78	4235	Failure to develop
Shout wall shout 2	14.61	4.3	47.2	Weak water invasion	6.05	3600	Failure to develop
75 grams of gas reservoir	11.75	17.57	79.02	Edge water	5.31	3200	Failure to develop
23 n1j YaHa	15.56	184.6	633	Edge water	3.35	4965	Gas injection development
YaHa 23 e + K	13.78	3.08	572	Bottom water	6.28	5152	Gas injection development
DE	23.21	352.42	36	Strong bottom water	2.61	4340	Failure to develop
YaKeLa	13.24	70.26	252	Edge-bottom water	6.36	5200	Failure to develop
Big dalaoba	16.64	59.36	593.6	Edge-bottom water	5.47	5000	Failure to develop
Tahe AT1	23.46	829.12	354	Strong bottom water	4.17	4400	Failure to develop
The British buy 7	19.68	1078	186	Bottom water	13.8	4690	Failure to develop
YuDong 2	17.43	73	198	Edge water	7.19	4690	Failure to develop
YangDaKe	18.26	174	121	Edge-bottom water	16.35	5050	Failure to develop
Shaxi temple, Xinchang	10.43	0.2	4.6	Nothing	2.42	2400	Failure to develop

CONCLUSION

In this paper, seven parameters including porosity, permeability, reserves abundance value, reservoir depth, condensate oil content, edge and bottom water energy and development mode are selected to establish the membership criteria for the fuzzy evaluation of condensate gas reservoirs. By selecting the relevant parameters of 18 condensate gas reservoirs in China, the comprehensive evaluation value B is obtained by using fuzzy mathematical evaluation method on the basis of single factor evaluation, and then the condensate gas reservoirs are divided into four categories: B 0.6, which is A type of condensate gas reservoir; 0.5 B $<$ 0.6 is a type two condensate gas reservoir; 0.4 B $<$ 0.5, third type of condensate gas reservoirs; B $<$ 0.4 is fourth type of condensate gas reservoirs. The practice shows that the factors considered in this classification and evaluation method are more comprehensive and the evaluation results are more scientific, so the evaluation results can lay a theoretical foundation for the evaluation of the development effect of condensate gas reservoirs in China.

Table 2: Results of comprehensive classification and evaluation of different condensate gas reservoirs.

Name of condensate gas reservoir	Comprehensive evaluation results	Type of condensate gas reservoir
The British buy 7	0.66	A class
23 n1j YaHa	0.65	
River	0.61	
YangDaKe 1	0.61	
YaHa 23 e + K	0.60	
Tahe AT1	0.60	The second
DE	0.57	
YuDong 2	0.54	
YaKeLa	0.50	
Call graph wall call 2	0.47	Third type
Basin of 5	0.44	
75 grams of gas reservoir	0.43	
Big Dalaoba	0.41	
DX10	0.37	Fourth type
DX14	0.36	
Shaxi temple, Xinchang	0.36	
DX17	0.31	
DX18	0.28	

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