CSCanada
Advances in Petroleum Exploration and Development
Vol. 6, No. 2, 2013, pp. 46-50
DOI:10.3968/j.aped.1925543820130602.1812

ISSN 1925-542X [Print]
ISSN 1925-5438 [Online]
www.cscanada.net
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The Analytic Hierarchy Process for the Reservoir Evaluation in Chaoyanggou Oilfield

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Received 2 November 2013; accepted 16 December 2013

Abstract
Reservoir evaluation is one of important contents in the reservoir study. This paper has adopted cluster analysis method to optimize evaluation parameters of low permeability reservoir and the analytic hierarchy process (AHP) to determine the weight coefficient. Moreover, this paper has made the reservoir comprehensive quantitative evaluation for low permeability reservoir of Chaoyanggou oil field. According to the cumulative probability curve, the evaluation results can be divided into three categories, which conform to the low permeability reservoir characteristics of Chaoyanggou oilfield. The method of reservoir comprehensive quantitative evaluation has solved the problems of single-factor classification evaluation that the evaluation result is not unique and provided favorable basis for low permeability reservoir evaluation of Chaoyanggou oilfield.

Key words: Reservoir evaluation; Weight coefficient; Low permeability reservoir; Analytic hierarchy; Cluster analysis

Liu, B. (2013). The Analytic Hierarchy Process for the Reservoir Evaluation in Chaoyanggou Oilfield. *Advances in Petroleum Exploration and Development*, *6*(2), 46-50. Available from: URL: http://www.cscanada.net/index.php/aped/article/view/j.aped.1925543820130602.1812 DOI: http://dx.doi.org/10.3968/j.aped.1925543820130602.1812

INTRODUCTION

With the deepening development of the Chaoyanggou oilfield, most of the blocks have entered a development adjustment stage. Because the influential factors of reservoir geological characteristics are complex and multifaceted[1], only making the reservoir comprehensive evaluation can improve the success rate of drilling, which has provided reliable geological basis for the formulation of development plan, development dynamic analysis, reservoir engineering study, reservoir numerical simulation and development plan adjustment.

1. THE GEOLOGICAL CHARACTERISTICS OF THE STUDY AREA

Chaoyanggou oilfield is a typical low porosity and low permeability oilfield, in which the seepage ability is poor[2-3] and the heterogeneity is serious. The Fuyang reservoir in Chaoyanggou oilfield mainly develops river facies. The lithology of Fuyang reservoir is mainly mudstone and sandstone. The single layer sandstone thickness is 3.8 m on average. The sand body is mainly given with narrow stripes and intermittent strip channel. The width of the sand body is from 300 to 600 meter. Reservoir porosity is about 16% on average, and the air porosity is generally 10.7×10^{-3} μm^2. The pore types include primary interranular pore, remaining intergranular slot form intergranular pore, dissolution and intergranular hole. The intergranular pore accounting for 64% is the main reservoir space in Fuyang reservoir. The corrosion hole and the intergranular hole are secondary reservoir space in Fuyang reservoir and have few holes. Fuyang reservoir has small pore throat[4-6] and big pore throat ratio. In Fuyu reservoir, the average pore radius is 1.28 mm and the average crude oil viscosity is 9.4 mPa.s. In Yangdachengzi reservoir, the average crude oil viscosity is 18.0 mPa.s and the crude oil density is 0.834 t/m^3. Compared with the Fuyu oil layer, the formation oil viscosity of Yangdachengzi reservoir increased obviously.

2. LOW PERMEABILITY RESERVOIR EVALUATION PARAMETER OPTIMIZATION

With low porosity, low permeability and high water saturation characteristics[7] in Chaoyanggou oilfield, the fluid seepage characteristics in the pores are nonlinear. Therefore, in order to make a reservoir evaluation of the low permeability reservoir, the evaluation parameters need selecting according to reservoir properties and fluid seepage characteristics. There are seven evaluation parameters, including permeability, porosity, effective thickness, reserve abundance, starting pressure gradient, movable fluid saturation, mean pore radius and mobility, which can show the features of the low permeability reservoir in Chaoyanggou oilfield. If so many parameters are involved in the evaluation, it must cause great difficulties in the evaluation work. Thus, this paper adopts the cluster analysis method[8] to evaluate the relationship between the parameters, remove similar parameters and select parameters with representative, comparability and usefulness to reach the purpose of parameter optimization.

After clustering analysis algorithm, the following results are obtained (Table 1).

Table 1
Clustering Results of Geologic Parameter in Fuyang Reservoir of Chaoyanggou Oilfield

T Similar degree	I The parameter I	J The parameter J	Distance
1	5	3	0.00663
2	6	1	0.02450
3	8	1	0.04016
4	3	1	0.31705
5	4	2	0.60162
6	7	2	0.60234
7	2	1	0.65855

In Table 1, the parameter 1, 2, 3, 4, 5, 6, 7 and 8 respectively represent permeability, porosity, effective thickness, abundant reserve, starting pressure gradient, movable fluid saturation, the average pore radius and mobility. In order to compare and optimize parameters, we mapped the clustering tree of geologic parameter in Fuyang reservoir.

Seen from Figure 1, the correlation coefficient between starting pressure gradient and the effective thickness is the largest and the correlation coefficient between permeability and movable fluid saturation is the second largest. As well known, the effect of starting pressure gradient is greater than the effect of effective thickness. Thus, the effective thickness parameter is eliminated. Similarly, having less effect than permeability variable, movable fluid saturation parameter is eliminated. Therefore, the remaining six parameters are the permeability, porosity, reserve abundance, starting pressure gradient, the average pore radius and mobility.

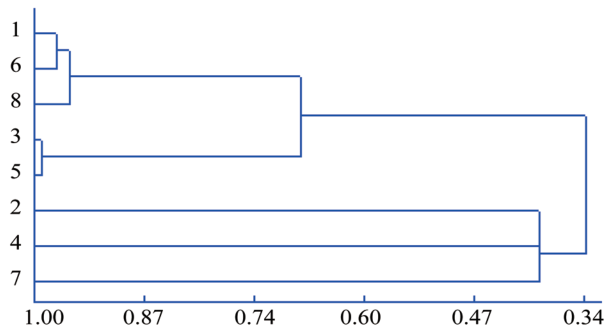

Figure 1
The Clustering Tree of Optimization Parameters in Fuyang Reservoir

These six optimized parameters not only have macro characteristic parameters but also have micro characteristic parameters. In these six optimized parameters, permeability, porosity and reserve abundance can reflect the reservoir physical property, the average pore radius can reflect the characteristics of pore structure, and starting pressure gradient only exists in low permeability reservoir. It can be seen that the selected parameters can reflect all the characteristics of low permeability reservoir.

3. THE SINGLE-FACTOR CLASSIFICATION EVALUATION OF LOW PERMEABILITY RESERVOIR

According to cluster analysis method, six parameters, including the permeability, porosity, reserve abundance, starting pressure gradient, the average pore radius and mobility, were selected to take part in the evaluation. In the process of determining the classification boundary, the classification function of the cumulative probability curve was used.

According to the cumulative probability curve, the boundary classification was determined and theclassification results were shown in the following table.

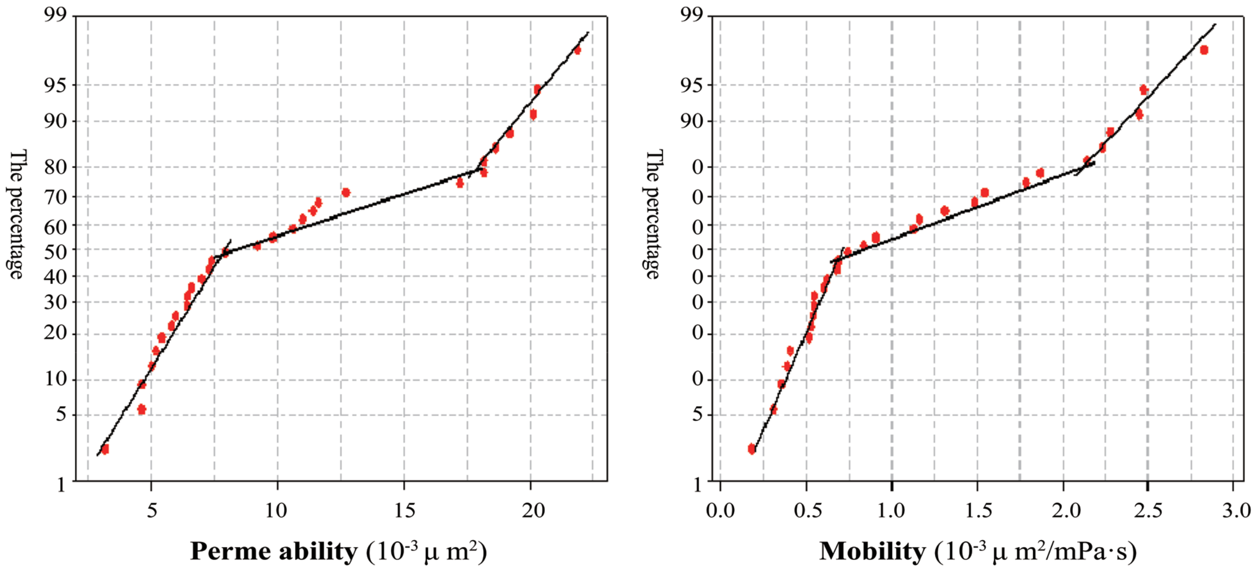

Figure 1
The Permeability and Mobility Cumulative Probability Curves

Table 1
The Single-Factor Classification Results

Block	Permeability	Porosity	Reserve abundance	Starting pressure gradient	The average pore radius	Mobility
Chaoqi 3 block	II	II	I	I	I	I
Yangdacheng reservoir	III	II	I	II	I	III
C-5 Fault	I	I	I	I	I	I
C-661-N block	I	II	I	I	I	I
C-45 Fault	I	I	I	I	I	I
C-601 Fault	II	II	I	I	I	II
The eastern test area	III	II	I	III	III	III
The axis part of C-50 block	I	I	II	I	I	I
C-46 block	II	II	II	I	I	II
Zhaozhou	III	II	II	II	III	III
C-2-D block	II	II	II	I	I	II

Seen from the single-factor classification results, the same block had different classification results by using different parameters. Therefore, the single-factor classification can not fully reflect the nature of the block. Meantime, it is easy to appear the classification results are not unique and the evaluation results are often not very accurate. Especially, when too many parameters are involved, using single-factor classification evaluation can lead to contradictory classification results.

Thus, we need to choose some parameters which can represent the reservoir characteristics to make a comprehensive classification evaluation for the reservoir.

4. MULTI-FACTOR COMPREHENSIVE EVALUATION METHOD OF LOW PERMEABILITY RESERVOIR

4.1 Fundamental Principles

Based on the reservoir evaluation parameter selection, the reservoir comprehensive quantitative evaluation makes a comprehensive analysis for the multiple influence factors of the reservoir and gets a comprehensive evaluation index. According to this evaluation index, reservoir was classified.

Here, the computation equation of the comprehensive evaluation index is as follows[10]:

$$REI = \sum_{i=1}^{n} a_i X_i \tag{1}$$

The equation: REI—Reservoir comprehensive evaluation index;

X_i— Reservoir evaluation parameters;

a_i — The weight coefficient of reservoir evaluation parameters;

n — The number of reservoir evaluation parameters.

Seen from the Equation (1), X_i is the known parameter while only a_i is unknown parameter. As long as a_i is calculated, REI can be calculated.

4.2 The Methods to Determine Weight Coefficient

(1) The AHP

A complex system can be always expressed as the form of feedback hierarchical structure. Based on the dependency structure of the system, the structure of a complex system can be decomposed to hierarchy structure and circular hierarchy[9]. Reservoir heterogeneity determines the value of various parameters with heterogeneity characterization. In versus, each parameter with heterogeneity characterization also determines the reservoir heterogeneity. Regarded as independent circular hierarchy in the internal, reservoir comprehensive quantitative evaluation system studies and determines the relative importance of the evaluation parameters (weight coefficient).

(2) To construct judgment matrix

According to the AHP principles, the hierarchy structure of reservoir comprehensive quantitative evaluation system has been established. For different reservoir parameters and formations, the comparative judgment matrixes and super matrix W have been constructed.

$$W = \begin{vmatrix} w_{11} & w_{12} & \bullet & w_{1N} \\ w_{21} & w_{22} & \bullet & w_{2N} \\ \bullet & \bullet & \bullet & \bullet \\ w_{N1} & w_{N2} & \bullet & w_{NN} \end{vmatrix} \tag{10}$$

In the Equation (10), W_{ij} represents relative rank weights comparing two sort (I, j = 1, 2, …, N)

(3) Weight coefficient calculation

Weight coefficient calculation, is actually to solve the scheduling problem with the limit of the super matrix W.

$$W = \begin{vmatrix} 0 & 0 & 0 & \cdots & 0 & w_{1N} \\ w_{21} & 0 & 0 & \cdots & 0 & 0 \\ 0 & w_{32} & 0 & \cdots & 0 & 0 \\ \vdots & & & & & \vdots \\ 0 & 0 & 0 & \cdots & w_{NN-1} & 0 \end{vmatrix} \tag{11}$$

For Equation (11), calculating the limit can get weight coefficient.

5. APPLICATION

In combination with the characteristics of low permeability reservoir, the hierarchical analysis method was applied to evaluate Fuyang reservoir of Chaoyanggou oilfield. The evaluation results were listed in the following table.

The evaluation indexes were classified according to cumulative probability curves.

Table 2
Comprehensive Evaluation Indexes (Simple Form)

Block	Analytic hierarchy evaluation index
Test area	0.7289
The C-2 Fault axis	0.4742
C-45 Fault	0.7666
C-202 Fault axis	0.4963
C-202 Fault wing	0.4141
C-5 Fault	0.7564
C-44-B Block	0.6624
C-64 Fault	0.7018
C-2-D Fault	0.4295
C-5-B Fault	0.696

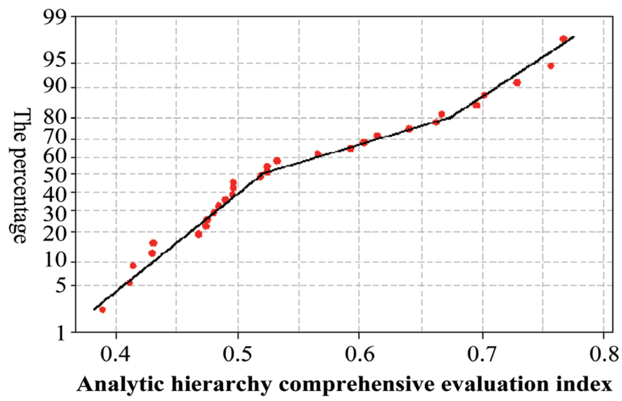

Figure 2
The Cumulative Probability Curves of Comprehensive Evaluation Index

Seen from the table clearly, the evaluation index was obviously divided into three segments, which determined the classification boundary. A specific classification was carried out.

Table 3
The Classification Boundary of Comprehensive Evaluation

Type	I	II	III
The comprehensive evaluation index of the AHP	>0.70	0.52~0.7	<0.52

Table 4
The AHP Classification

Block	The AHP Classification
Test area	Ⅰ
C-2 Fault axis	Ⅲ
C-45 Fault	Ⅰ
C-202 Fault axis	Ⅲ
C-202 Fault wing	Ⅲ
C-5 Fault	Ⅰ
C-44-B Block	Ⅱ
C-64 Fault	Ⅰ
C-2-D Fault	Ⅲ

In Class Ⅰ, there are 11 blocks with best reservoir permeability and porosity. Permeability is generally greater than 17×10^{-3} μm^2. The oil mobility is generally greater than 2×10^{-3} μm^2/mP·s. With lower underground oil viscosity, Class Ⅰ has higher reserve abundance whose average value is 76×10^4 t/km^2.

In Class Ⅱ, there are 11 block with better reservoir porosity and permeability which is generally greater than 8-17×10^{-3} μm^2. The oil mobility is generally greater than 0.6-2×10^{-3} μm^2/mP·s. The average value of reserve abundance is about 70×10^4 t/km^2. The underground oil viscosity is slightly higher than that of Class Ⅰ.

In Class Ⅲ, there are five blocks, belonging to low permeability reservoirs. Permeability is less than 7×10^{-3} μm^2 and the oil mobility is generally less than 10×10^{-3} μm^2/mP·s. The average value of reserve abundance is 64×10^4 t/km$^{2.}$ The underground oil viscosity is low and the porosity is poor. From a development perspective, because the starting pressure gradient exists in the reservoir, during the water injection development, driving pressure difference overcome not only the resistance of water driving but also the additional resistance caused by the starting pressure gradient. Development effect In Class Ⅲ is poorer than Class Ⅰ and Class Ⅱ.

CONCLUSION

(1) Taking into account the correlation between the parameters, the cluster analysis can optimize the parameters which can reflect all the characteristics of the reservoir and use fewer parameters to comprehensively reflect the characteristics of the reservoir.

(2) By using different parameters, the same block had different classification results. Therefore, the single-factor classification can not fully reflect the nature of the block. Meantime, it is easy to appear the classification results are not unique and the evaluation results are often not very accurate. Especially, when too many parameters are involved, using single-factor classification evaluation can lead to contradictory classification results.

(3) The comprehensive quantitative evaluation method is adopted to make a comprehensive classification evaluation for the Fuyang reservoir of Chaoyanggou oil field and the evaluation results can be divided into three categories. In Class Ⅰ, comprehensive evaluation index of the AHP is greater than 0.7; In Class Ⅱ, comprehensive evaluation index of the AHP is between 0.52 and 0.7; In Class Ⅲ, comprehensive evaluation index of the AHP is lower than 0.52. Evaluation results conform to the low permeability reservoir characteristics of Chaoyanggou oil field.

(4) The comprehensive quantitative evaluation method has solved the problems of single-factor classification evaluation that the evaluation result is not unique and provided favorable basis for low permeability reservoir evaluation of Chaoyanggou oilfield.

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