Research on Evaluation System of Water flooding Development Effect Based on Geological Classification

Yu Kaichun[1,2,a], Li keman[3,b], Chen Xinyu[3,c],and Zhang Jicheng[3,d]

[1] Department of Earth Sciences, Zhejiang University, Hangzhou, 310027;

[2] The fifth Oil Production Factory, Daqing Oil Field Company, Daqing, 163000, China

[3] College of Petroleum Engineering, Northeast Petroleum University.Daqing, 163318, China

[a] ykaichun@petrochina.com.cn, [b] 13795052912@163.com , [c]AidenChan163.com ,[d]Zhangjc777@163.com

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Abstract. With the better understanding of oilfield and the adjustment of the development modes, real water-flooding development effectiveness of reservoir depends on its basic geological condition, as well as the level of development technology and human factors. It is unable to judge the effect of development accurately by contrasting among one or several indexes directly. This paper will take Xingnan Oilfield as an example, building evaluation index system based on objective weight method combined by fuzzy comprehensive evaluation, under the background of geological settings and developing course of the oilfield. It will first evaluate the geological classification and then developing effective classification by judging the effect of artificial water drive quantitatively and building a kind of new evaluation method of water-flooding development effectiveness based on geological classification.

Introduction

When the reservoir exploitation enters into the middle-later periods, the circumstances always including water-cut rise, production decline, residential oil's spontaneous distribution and so on[1]. It is necessary to evaluate the early development strategy of reservoirs reasonably, making clear the developing course and status and finding out the contradiction during the process[2]. We should formulate the corresponding policy of development technology and take the essential measures for adjustment. Then, we must try to turn the situation of production decline around, and reduce the water-cut increasing level[3-5].

The reservoir of Xingnan Oilfield has the severe heterogeneity horizontally and vertically. There is a huge difference of geological feature among the blocks[6,7].The level of development technology is high or low, and factors controlled by human are different. The relations among factors are complicated that some are unable to accurately evaluate the influence degree of developing effects and judge the effect of development precisely by direct contrast among one or several indexes[8,9].

Therefore, this paper taking the reservoir engineering method, building an evaluation index system based on objective weighting method combined by fuzzy comprehensive evaluation, and carrying on the study about evaluation method of water-flooding development effectiveness. It will first evaluate the geological classification and then developing effective classification by judging the effect of artificial water drive quantitatively[10].That will provide scientific basis and technical support for developing adjustment of LaSaXing Oilfields at high water cut stage.

Analyzing and selecting evaluation index qualitatively

Through selecting common indexes of oilfield developing evaluation and analyzing the practical sense of its calculation method and evaluation content, it categorizes the indexes into two groups: geological characteristic factors and development effectiveness. According to reservoir engineering method and considering the maneuverability of index calculation, we should try to reserve an index with high relativity on the basis of index's definition and relationship. That will exclude visualized correlation between any two indexes.

Selecting geological characteristic factors. The factors which influencing geological feature including some aspects as Fig.1:

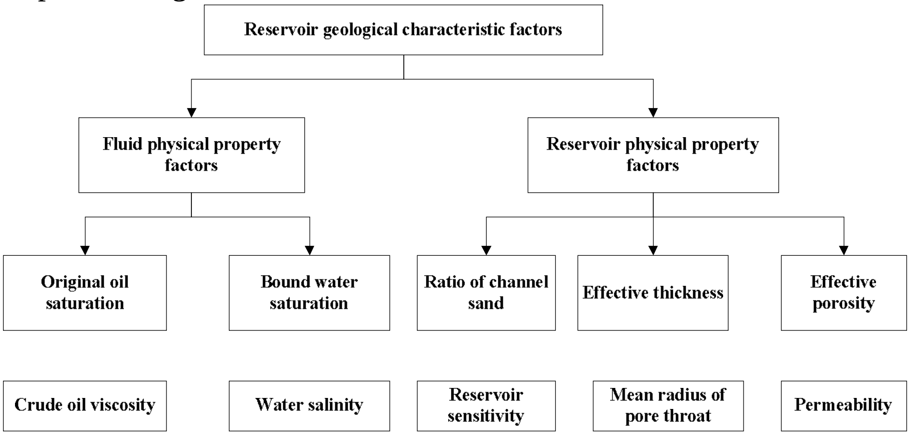

Fig.1 The selection of geological evaluation indexes

Through analysis, we select effective porosity, permeability, effective thickness, ratio of channel sand and original oil saturation as geological evaluating indexes.

Selecting factors of water-flooding development effect. By analyzing indexes reflecting dynamic properties of system, it can make sure the evaluation index system estimating the development effect and build a water-flooding development effect evaluation index system. The indexes are about the conditions of well pattern improvement, water injection, water-cut variation, oil production variation, fluid production variation and reserve production. They also include exploitation degree.

After experts deliberate it, they take same-well lapse rate、preserved reservoir pressure level,water-cut,recovery percent,increased rate of water cut as development effect evaluation indexes.

Analyzing and building comprehensive evaluation method quantitatively

Classified evaluation of single index/appraise the single index categorically. For the index of much higher and more superior, we take its average value as λ10. And, the number of blocks of which the mean value of target is over λ10 is A1, and their medium value is λ11;the number of blocks of which the mean value of target is belowλ10 is B1, and their medium value is λ12. We will take λ11, λ10, λ12 as threshold point to judge good, medium or bad of water-cut indexes.

For the index of much lower and more superior, we take its average value as λ20. And, the number of blocks of which the mean value of target is over λ20 is A2, and their medium value is λ21;the number of blocks of which the mean value of target is below λ20 is B2, and their medium value is λ22. We will take λ22, λ20, λ21 as threshold point to judge good, medium or bad of water-cut indexes.

Building the index degree of membership function.

(1)For the index of much higher and more superior, its degree of membership function is as Eq.1:

$$m_A(x)=\frac{x-a_{\min}}{a_{\max}-a_{\min}} \quad (a_{\min}\le x\le a_{\max}). \tag{1}$$

(2)For the index of much lower and more superior, its degree of membership function is as Eq.2:

$$m_A(x)=\frac{a_{\max}-x}{a_{\max}-a_{\min}} \quad (a_{\min}\le x\le a_{\max}) \tag{2}$$

Confirming the index weight. Weight determination method is mainly composed of subjective weight determination method and objective weight determination method. The former is the way how the experts reflect the long-term practical experience of appraising object. Most current literatures determine the weight of indexes by this method. In comparison, objective weight determination method considers the statistical property of indexes. It is determined by survey data. That avoids the influence of human factors. Therefore, it is extensively applied.

To determine the synthetic result of weight by variation coefficient method reflects better degree of discrimination. To determine the comprehensive result of weight by multiple correlation coefficient method reflects reasonable utilization of various target information and the result of confirming weight objectively. Geometric mean synthesis combines the two methods above and makes sure the final index weight. That can avoid the unilateralism of sole weight method.

The Method of Multiple Correlation Coefficients. Suppose evaluating index system as Eq.3.

$$X = \{x_1, x_2, \cdots x_m\} \tag{3}$$

Assume the given n groups of observed data including $x_1, x_2, \cdots x_m$. The number of the indexes is m as Eq.4.

$$\boldsymbol{A} = (\boldsymbol{x}_{\mathbf{ij}})_{\mathbf{n\times m}} = \begin{pmatrix} \boldsymbol{x}_{11} & \boldsymbol{x}_{12} & \mathbf{L} & \boldsymbol{x}_{\mathbf{1m}} \\ \boldsymbol{x}_{21} & \boldsymbol{x}_{22} & \mathbf{L} & \boldsymbol{x}_{\mathbf{2m}} \\ \mathbf{L} & \mathbf{L} & \mathbf{L} & \mathbf{L} \\ \boldsymbol{x}_{\mathbf{n1}} & \boldsymbol{x}_{\mathbf{n2}} & \mathbf{L} & \boldsymbol{x}_{\mathbf{nn}} \end{pmatrix}_{\mathbf{n\times m}} \tag{4}$$

The columns of the matrix represent the evaluating indexes of which the number is m, and the rows of the matrix represent the samples of which the number is n. For the given sample matrix A,the mean value and the variance of the indexes of Section k(k =1, 2, …, m)are:

$$\overline{x}_k = \frac{1}{n}\sum_{\mathrm{j}=1}^{n} x_{jk}, k = 1, 2, \cdots, m \tag{5}$$

$$s_{kk} = \frac{1}{n}\sum_{k=1}^{n}\left(x_{jk} - \overline{x}_k\right)^2, k = 1, 2, \cdots, m \tag{6}$$

the co-variance s_{ij} between the indexes of x_{i} and x_{j} is:

$$s_{ij} = \frac{1}{n}\sum_{k=1}^{n}\left(x_{ki} - \overline{x_i}\right)\left(x_{kj} - \overline{x_j}\right), 1 \le i \ne j \le m \tag{7}$$

We usually name the following matrix

$$S = \left(s_{ij}\right)_{m\times m} \tag{8}$$

as m matrix of the index assemble $\{x_1, x_2, \mathbf{L}, x_{\mathrm{m}}\}$.

On the basis of given sample data matrix, we will calculate the related matrix of index system:

$$R = (r_{\mathrm{ij}})_{\mathrm{m\times m}}, \qquad r_{\mathrm{ij}} = s_{\mathrm{ij}} / \sqrt{s_{\mathrm{ii}} s_{\mathrm{jj}}} \tag{9}$$

Studying the degree of linear association between xj and other indexes $\{x_1, \cdots x_{j-1}, x_{j+1} \cdots x_m\}$ is called multiple correlation coefficient, which is simply recorded as r_j.

According to the data sheet of multiple correlation coefficients, as Section k multiple correlation coefficients reflects the capacity to displace it of all the other indexes except it, the bigger it is and the smaller function it has. Therefore, we can take the reciprocal of multiple correlation coefficients as weight.

The formula of calculating weight with multiple correlation coefficients is:

$$w_k = \frac{\prod_{i=1}^{5} r_i^2}{r_k^2 \sum_{i=1}^{5} \prod_{j \neq i, j=1}^{5} r_j^2} \tag{10}$$

Variation co-efficient method. According to statistical principle, that the variance of each target is bigger indicates that the corresponding attribute of appraised object is stronger and that this attribute target must be laid more stress on. Thus, corresponding index weight should be larger in theory. This is the so-called variation co-efficient right. By calculating the index data of each block and mean value l_{v0} of each index, we can figure out standard difference $s = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(x_i - l_{v0}\right)^2}$ and variation co-efficient $V_i = \frac{s_i}{l_{v0}}$ based on its definition.

Determine the weight by variation co-efficient method:

$$w_i^2 = \frac{V_i}{\sum_{i=1}^{m} V_i} \tag{11}$$

Determining comprehensive weight. If we carry on the geometric mean of weight accounted by two methods above to get comprehensive weight for calculation, it will be more reasonable. Because it is able to avoid the unilateralism of calculating weight by each kind of method. The geometric formula is:

$$w_k' = \sqrt{w_k^1 w_k^2}, k = 1, 2, \cdots, 5 \tag{12}$$

Comprehensive weight calculated by normalization is:

$$w_k = \frac{w_k'}{\sum_{k=1}^{5} w_k'} \tag{13}$$

The method of multiple correlation coefficients asks for the quantity of sample is more than that of evaluation target. When sample quantity is less, this method will be not suitable for use anymore. Variation co-efficient method asks for that the mean value of each index is over 0. When the average value is no more than 0, it will be wrong in calculation. Therefore, when the problems come out during calculating weight, we should take the mean value $1/m$ of each index weight calculated by this method, and then put the value into the calculation formula of geometric mean to figure out comprehensive weight.

Comprehensive evaluation method and build classification standard. There are many factors influencing the oilfield development effect. In the index system composed of these targets, the relationship between them is complicated. Even more, some factors can not evaluate precisely the potential of oilfield water-flooding development and the evaluation results of each factor is not so exact. Aiming at the vagueness, we can use fuzzy comprehensive evaluation method in fuzzy mathematics to quantitatively evaluate the qualitative description on the factors influencing oil reservoir development condition. That will make the results more reliable.

Determining comprehensive evaluation method. After making sure the index degree of membership and weight of each target, we can use fuzzy comprehensive evaluation method to calculate comprehensive evaluation result of oilfield. Component operator is $M(\bullet, \oplus)$ and it belongs to weighted average type. It emphasizes weight and also adequately demonstrates the information of each evaluation index. The result of fuzzy evaluation is:

$$\tilde{D}^k = W \circ \Omega^k = (w_1, w_2, \cdots w_5) \circ (m_i^k)_{15} \quad (14)$$

Among that, $\Omega^k = (m_i^k)_{5?}$ is the result of fuzzy evaluation of the kth block.

$$\tilde{D}^k = w_1 \cdot m_1^k + w_2 \cdot m_2^k + w_3 \cdot m_3^k + w_4 \cdot m_4^k + w_5 \cdot m_5^k \quad (15)$$

By applying the formula, we can directly calculate the fuzzy evaluation results of reservoir geological condition in all the water-flooding blocks and require the definiteness comprehensive evaluation index of block's reservoir geological condition.

When block water-flooding development effect is carried on, we should give overall consideration to the influence of it made by geological condition. Evaluating the blocks of different geological classification and after calculating synthetic evaluation index, we should add corresponding geological foundation score on the basis of it, and then we can get the final score of oilfield water-flooding development effect is shown in Table. 1.

Table. 1 Geological classification foundation score

geological condition classification	Basic score
Type I geological block	4
Type II geological block	3
Type III geological block	2
Type IV geological block	1

Determining evaluating classification standard. Different from maximum degree of membership principle of fuzzy evaluation method, carrying on the rank boundary division of comprehensive score of all the blocks, we should adequately considerate the influence of block's overall score made by single index evaluation result is shown in Fig.2.

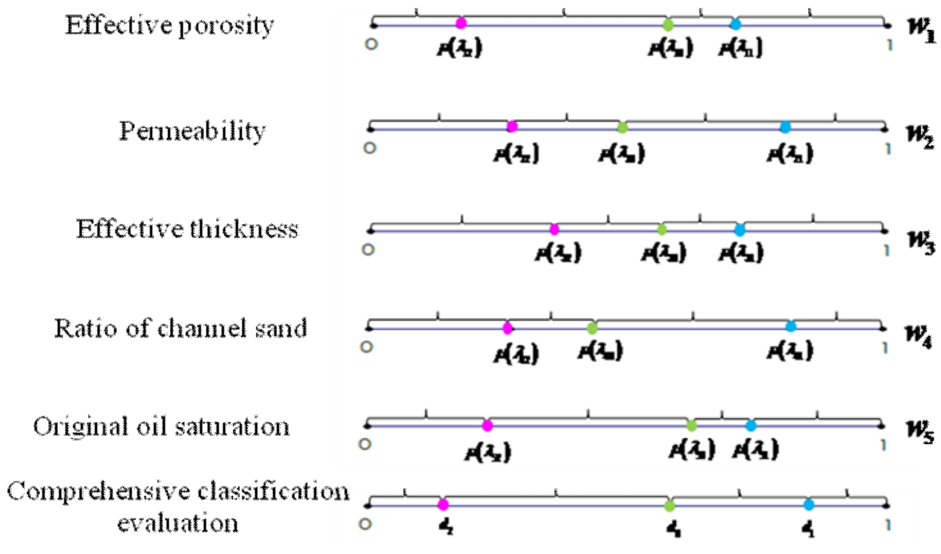

Fig.2 Sketch map of comprehensive evaluation classification

If $\tilde{D} = (d_0, d_1, d_2)$, there is:

$$d_i = (w_1 m(l_{1i}) + w_2 m(l_{2i}) + \cdots + w_5 m(l_{5i})), i = 0,1,2 \quad (16)$$

In it: w_i—each index weight;

$\mu(\lambda_i)$—each degree of membership of single index boundary point.

Taking $d_i(i=0,1,2)$ as the boundary point of good, medium and bad of fuzzy comprehensive evaluation result when we evaluate the reservoir geological condition of developed blocks is shown in Table. 2.

Table. 2 Comment rank standard

Comment rank	Bad	Lower-middle	Middle-upper	good
Quantitative value distribution	$(0, d_2]$	$[d_2, d_0)$	$[d_0, d_1)$	$[d_1, 1)$

We classify the blocks into the following four groups based on the value of the scores:

1. Class I block: the blocks of which evaluation result is good.
2. Class II block: the blocks of which evaluation result is middle-upper.
3. Class III block: the blocks of which evaluation result is lower-middle.
4. Class IV block: the blocks of which evaluation result is bad.

Calculating the classified boundary of development effect, we add corresponding basic score to different geological classification, and will get the boundary of blocks. The classification standard is is shown in Table. 3:

Table. 3 Evaluation standard of water-flooding development effect

Grade	Bad	Lower-middle	Middle-upper	good
Boundary of Class I	$(4, d_2^1]$	$[d_2^1, d_0^1)$	$[d_0^1, d_1^1)$	$[d_1^1, 5)$
Boundary of Class II	$(3, d_2^2]$	$[d_2^2, d_0^2)$	$[d_0^2, d_1^2)$	$[d_1^2, 4)$
Boundary of Class III	$(2, d_2^3]$	$[d_2^3, d_0^3)$	$[d_0^3, d_1^3)$	$[d_1^3, 3)$
Boundary of Class IV	$(1, d_2^4]$	$[d_2^4, d_0^4)$	$[d_0^4, d_1^4)$	$[d_1^4, 2)$

Example computation and analysis of the results

To test and verify reliability and maneuverability of method, we select 18 water-flooding blocks in Xingnan Oilfield to analyze. First, we calculate the geological evaluation index for each block. Second, we calculate its weight and degree of membership based on the result above. Third, we calculate comprehensive evaluation index with fuzzy evaluation method. Finally, we can get geological classification evaluation results, is shown in Table. 4 to Table. 7.

Table.4 Index weight of oilfield geological characteristics

Name of index	Effective porosity	Average permeability	Effective thickness	Ratio of channel sand	Original oil saturation
Weight	0.10259	0.26119	0.27018	0.23092	0.13512

Table. 5 Comprehensive evaluation index of oilfield geological characteristics

Name of block	Comprehensive evaluation index	Name of block	Comprehensive evaluation index
west of 10 pure oil development area	0.86039	13 pure oil development area	0.68968
east of 11 pure oil development area	0.8302	west of 11 pure oil development area	0.67134
west of 8 pure oil development area	0.78962	east of 8_12 transitional zone	0.38421
east of 9 pure oil development area	0.75901	Gaotaizi development area	0.37989
east of 10 pure oil development area	0.73227	Taibei development area	0.33169
east of 12 pure oil development area	0.73103	Gao 20	0.32342
west of 12 pure oil development area	0.72339	west of 8_12 transitional zone	0.25879
east of 8 pure oil development area	0.7206	13 transitional zone	0.19894
west of 9 pure oil development area	0.69503	Tai 19	0.14009

Table. 6 Comprehensive classification standard of oilfield geological characteristics

	Class four	Class three	Class two	Class one
Classification standard	(0，0.2554)	(0.2554，0.5694)	(0.5694，0.7739)	(0.7739，1)

Table. 7 Comprehensive evaluation result of oilfield geological characteristics

Name of block	Evaluation result
west of 10 pure oil development area	Class one Block
east of 11 pure oil development area	Class one Block
west of 8 pure oil development area	Class one Block
east of 9 pure oil development area	Class two Block
east of 10 pure oil development area	Class two Block
east of 12 pure oil development area	Class two Block
west of 12 pure oil development area	Class two Block
east of 8 pure oil development area	Class two Block
west of 9 pure oil development area	Class two Block
13 pure oil development area	Class two Block
west of 11 pure oil development area	Class two Block
east of 8_12 transitional zone	Class three Block
Gaotaizi development area	Class three Block
Taibei development area	Class three Block
Gao 20	Class three Block
west of 8_12 transitional zone	Class three Block
13 transitional zone	Class four Block
Tai 19	Class four Block

We take January to December in 2013 as the time point of evaluating development effect, and calculate each water-flooding development index. And then we respectively calculate weight and degree of membership of the same geological classification blocks based on geological characteristic classification results. We use fuzzy evaluation method to calculate the comprehensive evaluation index of block's water-flooding development effect from January to December in 2013 and will be able to get the final score of block's development effect, is shown in Table 8 to Table10.

Table. 8 Final score of oilfield water-flooding development effect(from 1 to 12 in 2013)

Geological classification	Name of block	Final score
Class one Block	west of 10 pure oil development area	4.88083
	east of 11 pure oil development area	4.40539
	west of 8 pure oil development area	4.21064
Class two Block	east of 8 pure oil development area	3.54075
	east of 10 pure oil development area	3.48864
	west of 11 pure oil development area	3.47172
	west of 9 pure oil development area	3.44733
	east of 9 pure oil development area	3.44339
	13 pure oil development area	3.42205
	west of 12 pure oil development area	3.39657
	east of 12 pure oil development area	3.24476
Class three Block	east of 8_12 transitional zone	2.77558
	west of 8_12 transitional zone	2.54504
	Gaotaizi development area	2.41131
	Gao 20	2.35087
	Taibei development area	2.21395
Class four Block	Tai 19	1.57473
	13 transitional zone	1.42527

Table. 9 Comprehensive classification standard of oilfield water-flooding development effect (from 1 to 12 in 2013)

Geological classification	Class four	Class three	Class two	Class one
Class one Block	(4,4.1494)	(4.1494,4.3989)	(4.3989,4.7783)	(4.7783,5)
Class two Block	(3,3.2013)	(3.2013,3.3888)	(3.3888,3.6523)	(3.6523,4)
Class three Block	(2,2.1840)	(2.1840,2.4593)	(2.4593,2.8632)	(2.8632,3)
Class four Block	(1,1.0000)	(1.0000,1.5000)	(1.5000,2.0000)	(2.0000,2)

Table. 10 Comprehensive evaluation result of water-flooding development effect (from 1 to 12 in 2013)

Geological classification	Name of block	Evaluation result
Class one Block	west of 10 pure oil development area	Class one Block
	east of 11 pure oil development area	Class two Block
	west of 8 pure oil development area	Class three Block
Class two Block	east of 8 pure oil development area	Class two Block
	east of 10 pure oil development area	Class two Block
	west of 11 pure oil development area	Class two Block
	west of 9 pure oil development area	Class two Block
	east of 9 pure oil development area	Class two Block
	13 pure oil development area	Class two Block
	west of 12 pure oil development area	Class two Block
	east of 12 pure oil development area	Class three Block
Class three Block	east of 8_12 transitional zone	Class two Block
	west of 8_12 transitional zone	Class two Block
	Gaotaizi development area	Class three Block
	Gao 20	Class three Block
	Taibei development area	Class three Block
Class four Block	Tai 19	Class two Block
	13 transitional zone	Class three Block

Conclusions

The evaluation index system featuring oilfield geological characteristic condition and water-flooding development effect , through qualitatively analyzing main factors influencing oilfield water-flooding development effect. The system takes effective porosity, permeability, effective thickness, ratio of channel sand and original oil saturation as geological condition evaluation indexes and takes same-well lapse rate,preserved reservoir pressure level,water-cut,recovery percent,increased rate of water cut as development effect evaluation indexes.

(1)As geological condition and development period between the blocks are different, the influence of each evaluation target weight to oilfield water-flooding development effect is also different. This paper builds the standard of single index classified evaluation based on evaluating the reality of blocks with mean value analysis. It combines objective weight method and fuzzy comprehensive evaluation method. On the basis of single index classification evaluation, it formulates the block evaluation classification standard, and classifies geological characteristics and water-flooding development effect into four groups of good, middle-upper, lower-middle and bad. This method eliminates subjective randomness of weight value, and converts the past qualitative evaluation to quantitative evaluation. The evaluation results are more practical and objective.

(2)Taking 18 water-flooding blocks in Xingnan Oilfield for example, we test and verify this evaluation method, and find out that the results are up to block geological general situation and field production reality, and also are able to accurately reflect the real condition of developed blocks. This method has directive significance to effective evaluation of other water-flooding development blocks in our country.

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