CSCanada
Advances in Natural Science
Vol. 8, No. 1, 2015, pp. 65-69
DOI: 10.3968/6706

ISSN 1715-7862 [PRINT]
ISSN 1715-7870 [ONLINE]
www.cscanada.net
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Weight Determination of Static and Dynamic Influencing Factors of the Change of Waterflooding Oil Well Based on Grey Relational Analysis and Analytic Hierarchy Process

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Supported by the National Major Project "Large Oil Gas Field and CBM Development" (2011ZX05052-004); Special Fund (2011ZX05010-002); Project of Daqing Oilfield Limited Company (DQYT-0505003-2014-JS-305).

Received 12 January 2015; accepted 8 March 2015
Published online 26 March 2015

Abstract

LaSaXing oilfield has entered into the extra high water cut development stage, when analysising dynamic the static factors, production factors and dynamic factors that influence oil well change are more, only depended on the qualitative analysis, it is difficult to accurately judge the cause of oil well change, can not meet the urgent need of oilfield development. This paper selects the static and dynamic factors affect the oil well change, the weight of static and dynamic influencing factors of the change of waterflooding wells are determined using the grey correlation analysis and the analytic hierarchy process based on exponential scale. The practices show that the weight of static and dynamic factors of the oil well change that determined using this method is scientific and reasonable, accord with the actual of oilfield, and provide reliable basis for intelligent analysis of dynamic change of oil well.

Key words: Grey relational analysis; Analytic hierarchy process; Oil well change; Influencing factors; Weight

Wen, H., Liu, Y. K., Sun, N., Lu, J. Y., & Wu, J. F. (2015). Weight Determination of Static and Dynamic Influencing Factors of the Change of Waterflooding Oil Well Based on Grey Relational Analysis and Analytic Hierarchy Process. *Advances in Natural Science*, *8*(1), 65-69. Available from: http://www.cscanada.net/index.php/ans/article/view/6706
DOI: http://dx.doi.org/10.3968/6706

INTRODUCTION

LaSaXing oilfield has entered into the extra high water cut development stage, with the oilfield development deepening, the differences of interlayer employ gradually narrow, and because of the layer and well pattern crossed seriously, when analysising dynamic, involves a number of wells and data, including the static factors, production factors, dynamic factors and other factors. the differences between layers of second and third infilling wells that mainly develop the table thin and poor reservoir and the untabulated reservoir are similar, variation amplitudes caused by changes of water injection wells for oil wells are very small, some are dynamic changes of well caused by trace changes of multilayer, in the process of dynamic analysis, only relying on the qualitative analysis of people, it is difficult to accurately judge causes of oil well change, can not meet the needs of oilfield development. In view of this, the weights of static and dynamic factors of waterflooding oil well change urgently need to be accurately understood, and these provide reliable bases for intelligent analysis of oil well dynamic change.

1. SCREENING OF STATIC AND DYNAMIC FACTORS

1.1 The Selection Principle of Static and Dynamic Factors

It is important to choose what parameters as the static and dynamic characterization parameters of well change.

Through comprehensively analysing the Static and dynamic factors affecting well changes, and combining with theoretical analysis and expert experience, the static and dynamic factors set are established, static and dynamic factors should meet the following principles and requirements: (a) The regularity principle. Static parameters can highlight the characteristics of evaluation objective. The static parameter is greater, the possibility of influence on well change is greater; or static parameter is smaller, the possibility of influence on oil well change is greater; or static parameter is the best at a certain point, the more far away from the point, it is the worse. (b) Avoid the pursuit of "comprehensive". Generally believed that the more the parameters are, they are the better, but too many parameters lead to similarity of different parameter systems, it is very difficult to reflect the personality of the evaluation object. At the same time, too many parameters will bring many difficulties for weight distribution, data collection, normalization etc.. (c) The objective in mind. The static parameters must be consistent with evaluation targets, to avoid contradictions. (d) It is readily available to obtain data.

1.2 Static and Dynamic Factors Set

Through analysing the static and dynamic data of well, according to the geological factors affecting the dynamic, 6 static parameters of perforated layer of oil wells and water injection wells were selected, including the average effective thickness h, the average permeability k, the average porosity φ, well spacing L, the diversion coefficient kh/L, influencing coefficient of sedimentary connectivity type C_s etc.. Specifically, the effective thickness, porosity, permeability and other parameters can reflect the reservoir heterogeneity degree (Bing, 2011; Li, Liu, & Xu, 2010). These parameters can be divided into three categories: (a) Parameters describing the reservoir quality, including the effective thickness, porosity, permeability, etc.; (b) Parameters describing the reservoir geometry, such as influencing coefficient of sedimentary connectivity type; (c) Parameters characterizing the development conditions, such as well spacing; (d) Comprehensive parameters characterizing the fluid filtrational resistance (seepage velocity coefficient), such as diversion coefficient kh/L. Combined with field statistics and numerical simulation analysis, the three main static parameters including kh/L, porosity and influencing coefficient of sedimentary connectivity type C_s are established, these can fully reflect the information of the heterogeneity of static parameters (Figure 1).

Reservoir is a complex nonlinear grey system, various factors will make oil well change, reflected in the change of wellhead oil, liquid production, water cut, bottom hole flowing pressure, such as measures, the water flooding effect situation will cause the oil change. Through analysing the dynamic production data of oil and water wells, combined with the practical of oilfield, liquid production, oil production, water cut, bottom hole flowing pressure are selected (Figure 1).

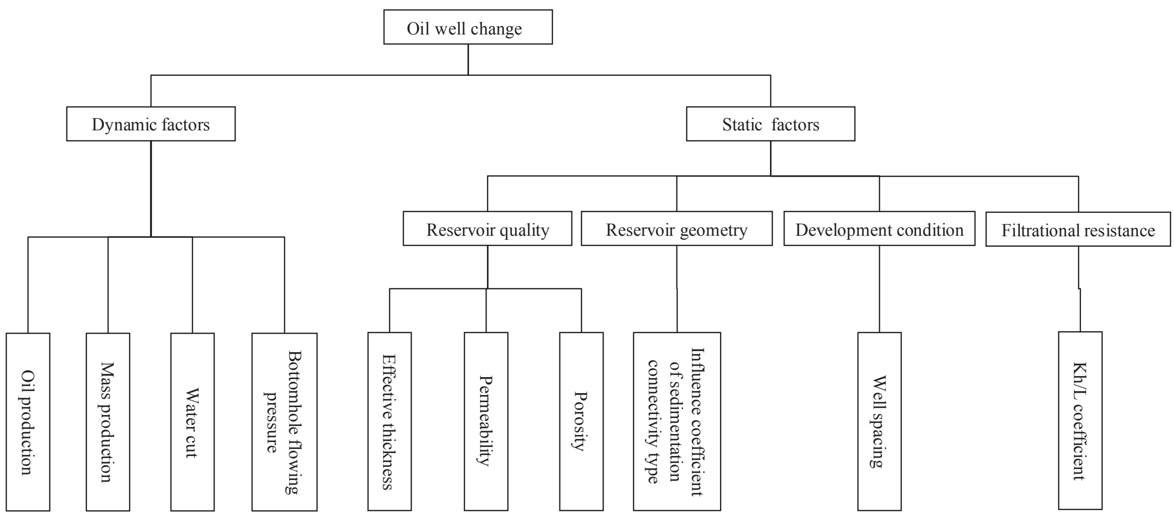

Figure 1
The Selection Frame of Static and Dynamic Factors

2. THE WEIGHT DETERMINATION METHOD OF FACTOR

2.1 Grey Relational Analysis Method

The grey relational analysis in the grey system theory provides a quantitative measurement method, very suitable for the analysis of dynamic process; it is the basis of grey system analysis, forecasting, decision-making. Including the selection of mother sequence and subsequence, and computing series of correlation coefficient, correlation degree, correlation order and correlation matrix (Sun, Wen, & Lu et al., 2008; Yang, Cheng, & Sun et al., 2003).

In order to analyze the relation between evaluation objects and their influence factors from the internal structure of data information, must use some quantitative index to quantitatively reflect the properties of evaluation objects. The number index according to certain order, called the mother sequence for relational analysis, denoted as:

$$\{X_t^{(0)}(0)\} \quad t=1, 2,..., n. \tag{1}$$

Sub sequence is orderly arrangement of the each sub factor that determines or influences property of evaluation objects, consider the m sub factors of the main factor, then the sub sequence is:

$$\{X_t^{(0)}(i)\} \quad i=1, 2,..., m; t=1, 2,..., n. \tag{2}$$

The mother sequence and subsequence of correlation analysis are determined, and the original data matrix can be constructed as follows.

$$X^{(0)} = \begin{bmatrix} x_1^{(0)}(0) & x_1^{(0)}(1) & \cdots & x_1^{(0)}(m) \\ x_2^{(0)}(0) & x_2^{(0)}(1) & \cdots & x_2^{(0)}(m) \\ \vdots & \vdots & \cdots & \vdots \\ x_n^{(0)}(0) & x_n^{(0)}(1) & \cdots & x_n^{(0)}(m) \end{bmatrix}. \tag{3}$$

Then the original data is normalized.

$$X_t^{(1)}(i)=X_t^{(0)}(i)/X_1^{(0)}(i). \tag{4}$$

In the formula, $t=1, 2,\cdots, n; i=1, 2,\cdots, m$.

The absolute difference and the extreme value between the observed values of each sub factors and the observed value of the main factor at same observation point are respectively calculated by the formula (5).

$$\begin{aligned} &\Delta_t(i,0) = | X_t^{(1)}(i) - X_t^{(1)}(0) | \\ &\Delta \max = \max_t \max_i | X_t^{(1)}(i) - X_t^{(1)}(0) | \\ &\Delta \max = \min_t \min_i | X_t^{(1)}(i) - X_t^{(1)}(0) | \end{aligned} \tag{5}$$

Therefore, the correlation degree between sub factors and main factor can be calculated by formula (5):

$$r_{i,0} = \frac{1}{n}\sum_{t=1}^{n}\frac{\Delta \min + \rho\Delta \max}{\Delta_t(i,0) + \rho\Delta \max}. \tag{6}$$

In the formula, ρ is called the resolution coefficient, which is 0.5.

Then, according to the normalization method, the weight coefficients of each index influence the change of oil well are obtained. The normalized expression is:

$$W_i = \frac{r_i}{\sum_{i=1}^{n} r_i}. \tag{7}$$

In the formula, W_i is the normalized weight coefficient.

2.2 Hierarchical Analysis Method Based on the Exponential Scale

The outstanding analytic hierarchy process (AHP) was proposed by USA operations research scientist Saaty at the beginning of the 70's in the twentieth Century. AHP make element is relative with the decision be decomposed into goals, standards, programs and other levels, which are a decision-making method for qualitative and quantitative analysis, this method has systemic, flexible and simple advantages.

2.2.1 Constructing Judgment Matrix and Assignment

P indicated judge matrix, *u* said factors, with *n* factors as examples. Comparing the two factors between them, constructing a $n\times n$ matrix:

$$P = \begin{bmatrix} \frac{u_1}{u_1} & \frac{u_1}{u_2} & \frac{u_1}{u_3} & \cdots & \frac{u_1}{u_n} \\ \frac{u_2}{u_1} & \frac{u_2}{u_2} & \frac{u_2}{u_3} & \cdots & \frac{u_2}{u_n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \frac{u_n}{u_1} & \frac{u_n}{u_2} & \frac{u_n}{u_3} & & \frac{u_n}{u_n} \end{bmatrix} = \begin{bmatrix} 1 & a_{12} & a_{13} & \cdots & a_{1n} \\ a_{21} & 1 & a_{23} & \cdots & a_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ a_{n1} & a_{n2} & a_{n3} & \cdots & a_{nn} \end{bmatrix}. \tag{8}$$

The above matrix is named judgment matrix, has the following characteristics: $a_{ij}>0$, $a_{ii}>1$.

Hierarchical analysis method was proposed by T. L. Saaty et al. used 1-9 scale to construct pairwise comparison matrix, the consistency of the effect is not ideal, and it has analysis fault. Therefore, this paper introduces a more accurate exponential scale to replace the 1-9 scale. The exponential scale is transitive, the rationality of scaling value make the average relative error be less than the other scale (Liu, Qiu, & Zhang, 1995; Hou & Shen, 1995). The exponential scale values and the corresponding meaning are shown in Table 1 and Table 2.

Table 1
Meaning Table of Importance Scale

a_{ij}	Illustration
a^0	The two elements are compared, they are the same important
a^2	Two elements are compared, the former is slightly more important than the latter
a^4	Two elements are compared. The former is obviously more important than the latter
a^6	Two elements are compared. The former is strongly more important than the latter
a^8	Two elements are compared. The former is extremely more important than the latter
a^1,a^3,a^5,a^7	The middle value of above adjacent judgment

Note. a=1.316, the ratio of the importance of *i* and *j* element is a_{ij}, then the ratio of the importance of *j* and *i* is $a_{ji}=1/a_{ij}$

Table 2
The Value of a^k

k	0	1	2	3	4	5	6	7	8
a^k	1	1.316	1.732	2.279	3	3.947	5.194	6.836	9
k	-1	-2	-3	-4	-5	-6	-7	-8	
a^k	0.76	0.577	0.439	0.333	0.253	0.193	0.146	0.111	

2.2.2 Solution of Judgment Matrix

The judgment matrix is a quantitative description of the decision-maker's subjective judgment, solution of judgment matrix is not required for high precision. Here, using the sum storing method.

(a) The A elements in the column are normalized, get the matrix $Q=(q_{ij})m\times m$. Among them, $q_{ij}=a_{ij}/\sum_{k=1}^{m}a_{kj}$.

(b) The Q elements according to the row are summed, get the vector $\alpha=(\alpha_1, \alpha_2,...,\alpha_m)^T$. Among them, $\alpha_i=\sum_{j=1}^{m}q_{ij}$.

(c) The vector α is normalized, get the weight vector $W=(w_1,w_2, \ldots w_m)^T$, among them, $w_i=\alpha_i/\sum_{k=1}^{m}\alpha_k$.

(d) The maximum eigenvalue is calculated with $\lambda_{\max}=\frac{1}{m}\sum_{i=1}^{m}\frac{(AW)_i}{w_i}$.

(e) The consistency index C_I is calculated

$$C_I=(\lambda_{\max}-n)/(n-1). \tag{9}$$

(f) The index is tested with random consistency in Table 3.

Table 3
Random Consistency Test Index Value of Exponential Scale

n	1	2	3	4	5	6	7	8	9	10	11	12	13
R_I	0.0	0.0	0.36	0.58	0.72	0.82	0.88	0.93	0.97	0.99	0.101	0.103	0.104

(g) The consistency is calculated with formula (10):

$$C_R=\frac{C_I}{R_I}. \tag{10}$$

The R_I values are referenced in Table 3, with the formula (9), C_R can be calculated, when $C_R<0.10$, that the consistency of judgment matrix is acceptable. The eigenvector W can be used as the weight coefficient of judgment index after normalization.

3. APPLICATION EXAMPLE

3.1 Weight Calculation of the Static Factor

Taking Xing ten district in Daqing Sanan Oilfield as an example, the influencing coefficient of sedimentary connectivity type C_s is used as a major influencing factor, porosity and kh/L are used as the sub factors. The data of 483 wells in the research area are processed, and the reservoir data of each center well and the surrounding oil wells are collected and analyzed, the inter well kh/L, porosity, influencing coefficient of sedimentary connectivity type C_s are computed, on the basis of the principle of grey correlation analysis, the grey correlation between sub factors and mother factors are analyzed, the grey relational degree of kh/L, porosity and sedimentary connection type influencing coefficient C_s are computed:

$$r=(0.793341,0.42732,1.0).$$

According to above results, the weight of kh/L, porosity and sedimentary connection type influencing coefficient C_s is:

$$W=(0.3573,0.1924,0.4503).$$

The weight of 3 main static factors of oil well change in Xing ten district was computed by using analytic hierarchy process ,according to the expert experience and repeated verification, and according to the important degree of parameters, the judgment matrix P is determined, and the weight of kh/L, porosity and the sedimentary connection type influencing coefficient C_s can be obtained.

$$P=\begin{pmatrix} & kh/L & \phi & C_s \\ kh/L & 1/1 & 3/1 & 1/1.316 \\ \phi & 1/3 & 1/1 & 1/3.948 \\ C_s & 1.316/1 & 3.948/1 & 1/1 \end{pmatrix}.$$

The weight of above each factor are got by using analytic hierarchy process is $W=(0.3775, 0.1258, 0.4967)$, $\lambda_{\max}=3$, matrix P is fully compatible, $C_I=0$, consistency test $C_R=0<0.1$, has consistency, the result is acceptable.

From the calculated results, the grey relational weight is relatively close to analytic hierarchy process weight, it may be considered that the result of grey calculation is reasonable. Average weight is $W=(0.3674, 0.1591, 0.4735)$.

3.2 Weight Calculation of the Dynamic Factor

The method is same with the calculate weight of static parameters, the weight of oil production, liquid production, water cut and flow pressure is respectively calculated by using the grey relational method, is $Q=(0.3519, 0.2484, 0.3186, 0.0811)$.

Based on the principle of analytic hierarchy process, firstly construct the judgment matrix P.

$$P=\begin{pmatrix} & oil & liq & fw & pwf \\ oil & 1/1 & 1.316/1 & 1/1 & 3.947/1 \\ liq & 1/1.316 & 1/1 & 1/1.316 & 3.947/1.316 \\ fw & 1/1 & 1.316/1 & 1/1 & 3.947/1 \\ pwf & 1/3.947 & 1.316/3.947 & 1/3.947 & 1/1 \end{pmatrix}.$$

Then the weight value of the oil production, liquid production, water cut and flow pressure are calculated by using the sum storing method, which is $Q=(0.3319,0.2522, 0.3319, 0.0841)$, $\lambda_{\max}=4$, the above matrix is completely compatible, $C_I=0$, consistency test $C_R=0<0.1$, this results is acceptable. The average weight of oil production, liquid production, water cut and flow pressure that influence dynamic change of oil well is $Q=(0.3419, 0.2503, 0.3253, 0.0826)$.

In the type of actual well change, oil well change may be that four dynamic parameters simultaneously change, or in which three dynamic parameters simultaneously change, or in which two dynamic parameters simultaneously change, or in which one dynamic parameter simultaneously changes, therefore, according to the weight result of oil production, liquid production, water cut and bottom hole flowing pressure, the weight of dynamic parameters in the research target should be adjusted and normalized, seen in Table 4.

Table 4
The Weight Adjustment Table of Dynamic Parameters of Oil Well

Dynamic parameters of oil well change	The weight of oil production, liquid production, water cut and bottom hole flowing pressure
Oil production, liquid production, water cut, botto mhole flowing pressure	(0.3419, 0.2503, 0.3253, 0.0826)
Oil production, liquid production, water cut	(0.3726, 0.2728, 0.3546, 0)
Oil production, producing fluid, botto mhole flowing pressure	(0.5067, 0.3709, 0, 0.1224)
The oil, water, botto mhole flowing pressure	(0.4560, 0, 0.4338, 0.1102)
Liquid production, water cut, bottom hole flowing pressure	(0, 0.3803, 0.4942, 0.1255)
Oil production, liquid production	(0.5773, 0.4227, 0, 0)
Water, botto mhole flowing pressure	(0, 0，0.7975, 0.2025)
Oil pressure, flow	(0.8054, 0, 0, 0.1946)
Produced fluid, bottom hole flowing pressure	(0, 0.7519, 0 0.2481)
Liquid production, water cut	(0, 0.4349, 0.5651, 0)
Oil production, water cut	(0.5124, 0, 0.4876, 0)
Oil-producing	(1, 0, 0, 0)
Liquid production	(0, 1, 0, 0)
Water cut	(0, 0, 1, 0)
Bottom hole flowing pressure	(0, 0, 0, 1)

CONCLUSION

(a) According to the selection principles of static and dynamic factors, three main static factors including *kh*/*L*, porosity and sedimentary connection type influencing coefficient C_s and four dynamic factors including oil production, liquid production, water cut, bottom hole flowing pressure of well change are comprehensively screened and established.

(b) The influence weights of static and dynamic factors are determined by using the grey relational analysis and hierarchical analysis methods based on exponential scale. The practice shows that, the influence weights of static and dynamic factors of oil well change were determined by this method are scientific and reasonable, also accord with the oilfield actual, and provide reliable basis for intelligent analysis of dynamic change of oil well.

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