Research Journal of Applied Sciences, Engineering and Technology 5(16): 4077-4081, 2013
DOI:10.19026/rjaset.5.4628
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: March 23, 2012 Accepted: December 13, 2012 Published: April 30, 2013

Research Article

Study on the Determination of Separated Layer Water Injection Based on Grey Correlation Analysis Method

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Abstract: How to determine the separated layer water injection is a problem which reservoir engineers concern in flood development oil field. These various influential factors of dividing coefficient method are analyzed in this study. Grey correlation analysis method is used to determine the dominant influential factors. And the weight of different dominant influential factors is determined, which realizes the quantitative comparison among them in dividing coefficient formula. This method considers the impact of these factors which are consist of the measure transformation coefficient, perforation thickness, injector producer distance, location coefficient and the number of injector and producer. The separated layer water injection formula is determined. The scientific and reasonable injection allocation is realized. The problem which the contradiction exists in the same layer or between the layer and the layer is obvious in the S block through combining with the current water injection development. The separated layer water injection method is proposed necessarily. The formula for water injection is determined by grey correlation analysis method in Block S. These factors considered are more with the actual situation. And the reasonable injection allocation is realized. It is directive and referenced for other oil field or block.

Keywords: Dividing coefficient, grey correlation, separated layer water injection, weight

INTRODUCTION

At present, domestic water distribution methods is mainly divided into two types which are macro-distribution and micro-distribution. Macro-distribution method is based on the whole oil field or block as the research object and according to the development pattern of the oil field or block to get the water distribution of the oil field or block (Xiong *et al*., 2004). Micro-distribution method is based on well group, the single well or layer segment as the research object, from the micro consideration cited correction coefficient to account the injection water quantity of single well or well group (Hong and Ji, 1992). Or using dividing coefficient to split with the shunt injection wells connected to all the production wells in the direction of the flow of liquid (Yan and Chen, 2007). Through the injection-production balance, the water injection of single water well is computed, or to split single water well of the water injection well to get layer segment distribution water (Li *et al*., 2005). But study on injection is relatively less in foreign. And United States J.L. Anthony and so on, who propose the method of displacement volume to distribute water injection and determine the large well group water flooding of optinomics master's thesis in Research of water injection rate (Anthony, 1992). United States P.M. Jarern and others apply Hearn and Hall curve on the new conversion well study of water injection rate (Jarren *et al*., 1992). The former Soviet Union P.M. caTTapBo, who has used statistical methods to study the effect of injection rate on fluid withdrawal rate (Cattapbo *et al*., 1991). Abroad most of these methods are micro-injection method.

These methods are mostly reflected badly in the specific formula for calculating the geological condition factor less and failed to make full use of existing monitoring data and production performance data and dividing coefficient of adaptability and practicality is worse. In this study, we consider the geological conditions, the combination of dynamic and static data to determine the main factors of affecting the dividing coefficient and the weight of each factor (Zhao, 2007), reasonable dividing coefficient of block is established, a reasonable stratified water injection formula of block injection wells is got, achieving rational distribution of

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single well of water injection well and increasing adjustment effect of water flooding.

THE THEORY OF GREY CORRELATION ANALYSIS METHOD

Grey correlation analysis method is a method of multivariate statistical analysis, by solving key relationships between various factors in the system, identifies important factors affecting target values and so as to master the main features of things. It is a quantitative description of a system development trend and comparison methods (Lian *et al*., 2006). It is based on the sample data for each factor, by gray correlation degree to describe the strength, the size and order of the relationship between various factors. If the sample data series reflects that the changed trend (direction, size, speed, etc.) of two factors are basically the same, the correlation degree between them is larger; conversely, it is smaller.

Deng julong put forward the grey system theory that has wide applications in areas such as oil and natural gas exploration and development (Deng, 1990). Grey correlation analysis of grey system theory is a quantitative description and comparison of methods of dynamic development trends. The dividing coefficient is as a grey system in this method, based on the sample data of various factors, by the correlation degree to describe the relationship between factors associated with strength, size and order. It may depend on chaos and timing sequential of the system to search for the evolution law of the system in the case of less data, so as to better determine the main factors, providing a theoretical basis for prediction and control of system. Grey correlation analysis generally requires the following five steps.

Determine the sequence of analysis: On the basis of analysis of the target variable of the research questions, to determine a dependent variable and multiple independent variables factors. The dependent variable data constitute the reference sequence, variable data constitute the comparative sequence, is expressed, respectively as formula (1):

$$\begin{aligned} \vec{y}_0 &= \left(y_0(1), y_0(2), \cdots, y_0(n)\right) \\ \vec{y}_1 &= \left(y_1(1), y_1(2), \cdots, y_1(n)\right) \\ &\cdots\cdots \\ \vec{y}_i &= \left(y_i(1), y_i(2), \cdots, y_i(n)\right) \end{aligned} \tag{1}$$

where,

$\vec{y}_0$ and $\vec{y}_i$ = Respectively as a reference sequence and compared sequence
n = The sequence's length
i = From 1 to m
m = The number of comparative sequence

The dimensionless of sequence: Because the physical significance of the various factors is different in the system, which will is lead to that the original variable sequence is with a different number of dimensions or levels. In order to ensure that all factors have rank and of equal weight, it is needed to be dimensionless. Dimensionless method is commonly used is initial value method and average method. Dimensionless sequence by application initial value and mean value method is expressed as formula (2):

$$x_j(k) = \frac{y_j(k)}{y_j(1)} \tag{2}$$

$$x_j(k) = \frac{y_j(k)}{\frac{1}{n}\sum_{k=1}^{n} y_j(k)} \tag{3}$$

where, j is from 0 to m, k = From 1 to n.
The new sequence after dimensionless is x_0 and x_1

Calculating correlation coefficient: Correlation coefficient is the data points of the i-th comparison sequence and reference sequences in the k-th degree of correlation, its expression is shown as formula (4):

$$\xi_{0i}(k) = \frac{\Delta_{\min} + \rho\Delta_{\max}}{\Delta_{0i}(k) + \rho\Delta_{\max}} \tag{4}$$

The $\Delta_{oi}(k)$ can be calculated by formula (5):

$$\Delta_{0i}(k) = \left|x_0(k) - x_i(k)\right| \tag{5}$$

where,

$\xi_{oi}(k)$ = Correlation coefficients
$\Delta_{oi}(k)$ = The absolute value of the i-th comparison sequence and reference sequences in the k-th degree of correlation
$\Delta_{\min}$ and $\Delta_{\max}$ = Respectively the minimum and maximum absolute difference of each data point
ρ = Resolution ratio
ρ = From 0 to 1, values from 0.1 to 0.5, usually is 0.5. Resolution coefficient is increased significance of difference between the correlation coefficient.

Calculating correlation degree: Because the number of correlation coefficient is many, the information is too scattered, for ease of compare, to compute an average of correlation coefficient, the correlation degree is the formula (6):

Table 1: The correlation degree of main factors

Classification	These main factors	Sort	Correlation degree
II	The measures transformation coefficient	1	0.6904
I	Perforation thickness	2	0.6865
II	Injector producer distance	3	0.6742
II	Location coefficient	4	0.6726
II	The number of injector and producer	5	0.6380

Table 2: The weight of main factors

These main factors	Weight values	These main factors	Weight values
The measures transformation coefficient	0.2054	Location coefficient	0.2
Perforation thickness	0.2042	The number of injector and producer	0.1898
Injector producer distance	0.2006		

$$r_{0i} = \frac{1}{n}\sum_{k=1}^{n}\xi_{0i}(k) \tag{6}$$

where, r_{0i} is correlation degree, the value is from 0 to 1

MAIN INFLUENCE FACTORS OF DIVIDING COEFFCIENT DETERMINED

In view of the current method of dividing coefficient calculation of many at home and abroad, identify the factors influencing the dividing coefficient values. It is found through analysis that many parameter (impact factor) introduced in dividing coefficient formula and there is no unified standard. Therefore, in order to better identify and divide the level of effect factors on the effect of dividing coefficient and how dividing coefficient, these influencing factors will be classified, including geological factors (I), controllable factors (II) and integrative factors (III) . Geological factors related to the status of the geological features, such as the permeability of layers, connectivity coefficient, the coefficient of interlayer interference, the affect coefficient of sedimentary facieses, the coefficient of permeability anisotropy, perforation thickness and so on. Controllable factors is the factor that is generated for the operation of people, such as the number of injector and producer, injector producer distance, the measures transformation coefficient, mining width coefficient and the location coefficient. The integrative factors is to consider the performance of the factors of injection wells and the surrounding characteristics of producing wells connected with it, such as the direction formation capacity. These main factors are determined by grey correlation analysis method. Dividing coefficient is established which considers the effect of various factors. Therefore the split result is more realistic.

Gray correlation analysis method to determine the main factors and weights: According to the actual water injection profile data of S well field, the layer water absorption is chose as the reference sequence. And permeability of layers, perforation thickness, connectivity coefficient and the coefficient of interlayer interference, injector producer distance, the measures transformation coefficient, mining width coefficient, the location coefficient, the number of injector and producer and the direction formation capacity are as comparison sequences. Using mean method to dimensionless, resolution ratio is 0.5 and the correlation degree of various factors is calculated. The main influencing factors are effective thickness, injection-production wells, injector producer distance, the measures transformation coefficient and the location coefficient through sorting. The values are in Table 1.

According to the correlation degree, the weight values are determined through normalization. It is shown in Table 2.

SINGLE-LAYERED WATER INJECTION FORMULA DETERMINED

The plane dividing coefficient and vertical dividing coefficient are established which taking into account all factors of weight depending on the selected main factors of S well field.

Plane dividing coefficient: Plane dividing coefficient to consider the weight of various factors is set up based on the selected five parameters. The formula is formula (7):

$$\gamma_i = \frac{\sum_{j=1}^{m}\left[\left(M_{ij}+\partial M_{ij}\right)\left(\alpha_{ij}+\partial\alpha_{ij}\right)\left(N_{ij}+\partial N_{ij}\right)\left(H_{ij}+\partial H_{ij}\right)/\ln\left(D_{ij}+\partial D_{ij}\right)\right]}{\sum_{i=1}^{n}\sum_{j=1}^{m}\left[\left(M_{ij}+\partial M_{ij}\right)\left(\alpha_{ij}+\partial\alpha_{ij}\right)\left(N_{ij}+\partial N_{ij}\right)\left(H_{ij}+\partial H_{ij}\right)/\ln\left(D_{ij}+\partial D_{ij}\right)\right]} \tag{7}$$

where, *m, n ,l* respectively is the total number of layer of *I* water injection well, the total number of injection wells and the number of water injection wells connected with *I* well .

M_{ij}, α_{ij}, N_{ij} respectively is the measures transformation coefficients of *j* of *I* water injection well, location coefficients and the number of injector and producer, they are dimensionless.

H_{ij} is the perforation thickness of *j* layer of *I* water injection well, the unit is meter, γ_i is dividing

coefficient of *I* water injection well, it is dimensionless and existing the formula (8):

$$\sum_{i=1}^{n} \gamma_i = 1 \tag{8}$$

$\partial_{ij}, \partial\alpha_{ij}, \partial N_{ij}$ respectively is the correction of the measures transformation coefficients, location coefficients and the number of injector and producer weight correction, they are dimensionless

$\partial H_{ij}, \partial D_{ij}$ respectively is perforation thickness and injector producer distance weight correction, the unit is meter.

The correction formula for various weights is formula (9):

$$\begin{aligned}
\partial M_{ij} &= \left(M_{ij} - \overline{M}\right)\left(w_{\mathrm{M}} - \frac{1}{n}\right)\cdot n \\
\partial \alpha_{ij} &= \left(\alpha_{ij} - \overline{\alpha}\right)\left(w_{\alpha} - \frac{1}{n}\right)\cdot n \\
\partial N_{ij} &= \left(N_{ij} - \overline{N}\right)\left(w_{\mathrm{N}} - \frac{1}{n}\right)\cdot n \\
\partial H_{ij} &= \left(H_{ij} - \overline{H}\right)\left(w_{\mathrm{H}} - \frac{1}{n}\right)\cdot n \\
\partial D_{ij} &= \left(D_{ij} - \overline{D}\right)\left(w_{\mathrm{D}} - \frac{1}{n}\right)\cdot n
\end{aligned} \tag{9}$$

where, $\overline{M}, \overline{\alpha}, \overline{N}, \overline{H}, \overline{D}$ respectively is the average of measures transformation coefficients, the average of location coefficients, the average of the number of injector and producer, the average of perforation thickness and the average of injector producer distance. And n is the number of influencing factors for the construction of dividing coefficient

$w_{\mathrm{M}}, w_{\alpha}, w_{\mathrm{N}}, w_{\mathrm{H}}, w_{\mathrm{D}}$ respectively is the weight of the measures transformation coefficients, location coefficients, the number of injector and producer, perforation thickness and injector producer distance after normalization based on the correlation degree value of each parameter.

Vertical dividing coefficient: According to the construction process of plane dividing coefficient, vertical dividing coefficient is established in accordance with the S water injection wells. The formula is shown as formula (10):

$$\beta_{ij} = \frac{\left[\left(M_{ij} + \partial M_{ij}\right)\left(\alpha_{ij} + \partial\alpha_{ij}\right)\left(N_{ij} + \partial N_{ij}\right)\right.}{\sum_{j=1}^{m}\left[\left(M_{ij} + \partial M_{ij}\right)\left(\alpha_{ij} + \partial\alpha_{ij}\right)\left(N_{ij} + \partial N_{ij}\right)\right.} \frac{\left.\left(H_{ij} + \partial H_{ij}\right)/\ln\left(D_{ij} + \partial D_{ij}\right)\right]}{\left.\left(H_{ij} + \partial H_{ij}\right)/\ln\left(D_{ij} + \partial D_{ij}\right)\right]} \tag{10}$$

where, β_{ij} is vertical dividing coefficient of *j* layer of *I* water injection well and it is existing the formula (11):

$$\sum_{j=1}^{m} \beta_{ij} = 1 \tag{11}$$

The Formula of Single Well Injection Allocation: After obtaining the well of plane dividing coefficient, water injection of single well injection allocation can be evaluated according to the plane dividing coefficient. The formula is shown as formula (12):

$$\begin{aligned}
Q_{\mathrm{iw}i} &= Q_{\mathrm{iw}}\gamma_i \\
&= Q_{\mathrm{iw}} \frac{\sum_{j=1}^{m}\left[\left(M_{ij} + \partial M_{ij}\right)\left(\alpha_{ij} + \partial\alpha_{ij}\right)\left(N_{ij} + \partial N_{ij}\right)\right.}{\sum_{i=1}^{n}\sum_{j=1}^{m}\left[\left(M_{ij} + \partial M_{ij}\right)\left(\alpha_{ij} + \partial\alpha_{ij}\right)\left(N_{ij} + \partial N_{ij}\right)\right.} \\
&\quad \frac{\left.\left(H_{ij} + \partial H_{ij}\right)/\ln\left(D_{ij} + \partial D_{ij}\right)\right]}{\left.\left(H_{ij} + \partial H_{ij}\right)/\ln\left(D_{ij} + \partial D_{ij}\right)\right]}
\end{aligned} \tag{12}$$

where,

Q_{iwi} = The number of single monthly injection of Well *I* injection well, the unit is $10^4 m^3$

Q_{iw} = The number monthly injection of total injection well, the unit is $10^4 m^3$

When injection allocation amount of each injection is determined, divided by total perforation effective thickness of each injection wells and the formula of water intensity of water injection well can be obtained, the formula is formula (13):

$$Q_{\mathrm{iwH}i} = \frac{Q_{\mathrm{iw}i}}{30 \times \sum_{k=1}^{m} h_k} \tag{13}$$

where,

$Q_{\mathrm{iwH}i}$ = The strength of well *I* injection well, the unit is $m^3/(m\cdot d)$

h_k = Effective thickness of *k* layer of well *I* injection well, the unit is meter

The formula of layer injection allocation: When getting single well injection allocation of water injection wells, the layer injection allocation can be computed according to vertical dividing coefficient, the formula is formula (14):

$$\begin{aligned}
q_{\mathrm{iw}ij} &= Q_{\mathrm{iw}i}\beta_{ij} \\
&= Q_{\mathrm{iw}i} \frac{\left[\left(M_{ij} + \partial M_{ij}\right)\left(\alpha_{ij} + \partial\alpha_{ij}\right)\left(N_{ij} + \partial N_{ij}\right)\right.}{\sum_{j=1}^{m}\left[\left(M_{ij} + \partial M_{ij}\right)\left(\alpha_{ij} + \partial\alpha_{ij}\right)\left(N_{ij} + \partial N_{ij}\right)\right.} \\
&\quad \frac{\left.\left(H_{ij} + \partial H_{ij}\right)/\ln\left(D_{ij} + \partial D_{ij}\right)\right]}{\left.\left(H_{ij} + \partial H_{ij}\right)/\ln\left(D_{ij} + \partial D_{ij}\right)\right]}
\end{aligned} \tag{14}$$

where, q_{iwij} is injection monthly volume of *j* layer of *i* injection well, the unit is 10^4m^3

CONCLUSION

Based on geology and development of the S well field, these influencing factors of dividing coefficient are analyzed, by grey correlation analysis method to determine the main impact factors. They are the measure reformation coefficient, perforation thickness, injector producer distance, location coefficient and the number of injector and producer. At the same time the weight values of various factors in the dividing coefficient are identified.

According to the weight value of main influence factors and the various factors, the plane dividing coefficient and vertical dividing coefficient are established. Constructing dividing coefficient is more in line with the actual situation of S well field.

Depending on the water injection rate of S well field, these formulas of single well and layer segment injection allocation are determined, to achieve the rationality of separate layer water injection;

Through the study on this method, the determination of the stratified water injection after water flooding work provides a quantitative standard. It has practical implications.

ACKNOWLEDGMENT

This author gratefully acknowledges financial support from Heilongjiang Provincial Science and Technology Plan Project (Grant No: GZ09A407) and Research Program of Innovation Team of Science and Technology in Enhanced Oil and Gas Recovery (Grant No: 2009td08).

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