The production split method in multilayer reservoir based on grey relational analysis

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Abstract. At present, production split methods mainly include effective thickness method, formation coefficient method and dynamic equation split method. On account of various factors restriction, the applied results are unsatisfactory. In order to fully grasp the multilayer reservoir layering exploitation status, a new production split method is established by utilizing grey relational analysis based on traditional production split methods. The new method divides the influence factors of single layer production split into static geological factor and dynamic development factor. We confirm correlation degree weight of static geological factor and dynamic development factor by utilizing grey relational analysis, which synthetically considers various production split influence factors. And finally a new production split method is established. Through actual applied verification, the new method is accurate and widely adaptable, which provides a new idea for production split work.

1. Preface

During the oil field exploitation, the current status of reservoir exploitation which guides adjustment exploitation plan, synthetically exploiting residual reserves and enhancing reservoir recovery ratio [1]. Only on the premises of fully grasping the oil well layering development status, can we take effective layering adjustment measures and exploiting residual reserves measures in multilayer reservoir. Therefore, layering production split is of significant applied value in the process of multilayer reservoir exact exploitation. A scientific and reasonable production split method can markedly enhance producing efficiency of multilayer reservoir exact exploitation. At present, layering production split technology mainly includes well testing method, production logging method, geologic analysis method and the like. The well testing method and production logging method are the most direct method with high accuracy but high cost. The geological analysis method is mainly based on the fine understanding of the reservoir, because of its low cost, it has been widely used. The field applied method of the geological analysis includes the effective thickness method (H method), the formation coefficient method (KH method) [2,3], and the dynamic equation split method (Ci equation method) [4-6] and so on. However, through theoretical analysis and practical applied tests, the different methods of production split differ greatly, which can’t guide the development of oilfields well. Therefore, it is significant to find an accurate and workable production split method, which is the key to grasp the current status of reservoir exploitation [7].

Based on the dynamic equation split (Ci equation) method, a new method of production split with considering the weight of static geologic parameters and dynamic development parameters is established by using the grey relational analysis method.
2. Traditional production split methods

2.1. Formation coefficient method

The production split equation of formation coefficient method is:

$$\beta_i = \frac{K_i H_i}{\sum K_i H_i}$$  \hspace{1cm} (1)

In the above formula:
- $H_i$ - Effective thickness of the No. $i$ layer, $m$;
- $K_i$ - Effective permeability of the No. $i$ layer, $mD$.

The parameter selection of formation coefficient method ($KH$ method) only considers the effect of effective thickness and permeability of reservoir, but does not consider the influence of interlayer interference and water flooding effect. It considers that all the effective thickness has contributed to production split. However, the data of water absorbing profile and oil producing profile show that there are some layers have little contribution or no contribution to production split, due to the influence of interlayer interference and the correspondence of oil well and water well. The formation coefficient method is more suitable for sandstone reservoir with short producing segment wells, less perforation layers and weaker reservoir heterogeneity. While it has poor applicability to the sandstone reservoir with stronger reservoir heterogeneity, long production segment wells and more perforation layers.

2.2. Dynamic equation split method

According to the principle of water flood oilfield injection-production balance, combined with reservoir conditions, oil displacement conditions and producing conditions, dynamic equation split method puts forward the calculation of stratified producing fluid (oil) quantity by counting injecting water quantity of injection well. The quantity of water injection will be split by the corresponding oil wells. The split ability is expressed by the concept of split coefficients. And the No. $i$ layer split coefficient $C_i$ is calculated by the formula below:

$$C_i = \frac{Y_i}{\sum Y_i}$$  \hspace{1cm} (2)

In the above formula, $Y_i$ is the value of layer split ratio, which is calculated by the following formula:

$$Y_i = K_i H_i Z_i G_i K_{sh} N_i / \ln D_i$$  \hspace{1cm} (3)

In the above formula:
- $K_i$ - Effective permeability of the No. $i$ layer, $\mu m^2$;
- $H_i$ - Effective thickness of the No. $i$ layer, $m$;
- $Z_i$ - Connected coefficient of oil and water well, dimensionless;
- $G_i$ - Interlayer interference coefficient, dimensionless;
- $K_{sh}$ - Sedimentary facies influence coefficient, dimensionless;
- $N_i$ - Number of water injection wells, dimensionless;
- $D_i$ - Distance of oil and water well, $m$.

The method considers various dynamic and static factors, which influences the water absorbing of layer. And the split result is in accord with the actual status of reservoir compared with the traditional $KH$ method. However, this method does not have a systematic study on the influence weight of dynamic and static factors. Some reservoir engineers simply copied this method without taking the specific geological conditions and development conditions of the oilfields into account, thus causing the split coefficient to be quite different from the actual fact. In this paper, based on dynamic equation...
split method, a scientific and reasonable study on the dynamic and static factors influence of the production split output is carried out by using the grey relational analysis method. Then a new calculating method of production split is determined.

3. Grey relational analysis model

3.1. Static geological factors
Static geologic factors are mainly concerned with the effect of effective permeability, effective thickness, exploitable oil saturation and sedimentary environment. The exploitable oil saturation is equal to 100% minus irreducible water saturation and residual oil saturation, which represents the amount of flowing oil in each layer. The sedimentary environment parameters are determined by the position of the oil well in the sand body. The thickness of sand layer at main channel is thick, and the oil well is in good connectivity. The sand layer at marginal channel has a small thickness and medium connectivity. The reservoir property of sand layer at outside channel is always very poor.

Table 1. Influence parameters of sedimentary environment

| Sedimentary environment | Main channel | Marginal channel | Outside channel |
|-------------------------|--------------|------------------|-----------------|
| Sedimentary parameter   | 0.8-1.0      | 0.5-0.8          | 0.2-0.5         |

The static geological factor weight \( C_{gi} \) of oil well at No. \( i \) layer. The calculating formula is as following:

\[
C_{gi} = \frac{Y_{gi}}{\sum Y_{gi}}
\]  

(4)

In the above formula, \( Y_{gi} \) is the value of No. \( i \) layer static geological weight split ratio, which is calculated by the following formula:

\[
Y_{gi} = K_i \cdot H_i \cdot S_{oi} \cdot \beta_i
\]  

(5)

In the above formula:

- \( K_i \) - Effective permeability of the No. \( i \) layer, \( \mu m^2 \);
- \( H_i \) - Effective thickness of the No. \( i \) layer, m;
- \( S_{oi} \) - Exploitable oil saturation, dimensionless;
- \( \beta_i \) - Sedimentary environment parameters, dimensionless.

3.2. Dynamic development factors
The dynamic development factors are mainly concerned with the influence of plane heterogeneity and water flood strength. The plane heterogeneity is mainly manifested in the permeability difference of oil wells corresponding to the injection well. According to the plane heterogeneous degree of surrounding oil wells, the plane heterogeneous parameters \( (F_i) \) of each oil well are between 0.2 and 1.0. The water flood strength of the oil well is mainly affected by the quantity of water injection wells, the water absorbing strength of each water injection well layer and the surrounding edge water strength of oil well. The final value of the water flood strength parameter is the sum of water absorbing strength parameter \( (W_i) \) and edge water strength parameter \( (E_i) \). The dynamic development influence parameters are shown in the table below:
Table 2. Water absorbing strength influence parameters

| Absorption strength | Weak  | Medium | Strong |
|---------------------|-------|--------|--------|
| Absorption parameter| 0.2-0.4| 0.5-0.7| 0.8-1.0|

Table 3. Edge water strength influence parameters

| Edge water strength | Weak  | Medium | Strong |
|---------------------|-------|--------|--------|
| Edge water parameter| 0.1-0.2| 0.3-0.4| 0.5-0.6|

The dynamic development factor weight \(C_{ei}\) of oil well at No. \(i\) layer. The calculating formula is as following:

\[
C_{ei} = \frac{Y_{ei}}{\sum Y_{ei}}
\]  \(6\)

In the above formula, \(Y_{ei}\) is the value of No. \(i\) layer dynamic development weight split ratio, which is calculated by the following formula:

\[
Y_{ei} = \left( \sum_{i=1}^{n} W_i + E_i \right) \times F_i
\]  \(7\)

In the above formula:
- \(W_i\) - Injection well water absorbing strength influence parameters of No. \(i\) layer, dimensionless;
- \(n\) - Number of water injection wells corresponding to oil well, dimensionless;
- \(E_i\) - Edge water strength influence parameters, dimensionless;
- \(F_i\) - Plane heterogeneous influence parameters, dimensionless.

3.3. Grey relational degree analysis

Grey relational degree analysis is an important component of grey system theory, which is a method to essentially replace the problem of infinite space with the problem of finite sequence. By analysing the development trend similarity or dissimilarity degree of each factor, the grey relational degree is used to measure the correlation degree of each factor.

3.3.1. Original sequence determination

The original sequence consists of one dependent variable and multiple independent variables. The dependent variable factor reflects the characteristics of the system, and the data of multiple samples constitute the reference sequence. The independent variable factor affects the system characteristics, and the data of each factor multiple samples can constitute a comparison sequence. In this paper, the dependent variable of the original sequence is the oil producing profile percentage of oil well each layer, as a reference sequence \(x_0\); the independent variable is the static geological weight and dynamic development weight of oil well each layer, as the comparison sequence of \(x_1\) and \(x_2\) respectively.

\[
x_0 = (x_0(1), x_0(2), x_0(3), \ldots, x_0(n))
\]

\[
x_j = (x_j(1), x_j(2), x_j(3), \ldots, x_j(n))
\]

\[
x_2 = (x_2(1), x_2(2), x_2(3), \ldots, x_2(n))
\]

\[
\ldots
\]

\[
x_i = (x_i(1), x_i(2), x_i(3), \ldots, x_i(n))
\]  \(8\)

In the above formula:
- \(x_0\) - Oil producing profile percentage of each layer, reference sequence;
- \(x_i\) - Static geological weight of each layer, comparison sequence;
$x_2$ - Dynamic development weight of each layer, comparison sequence;

$x_i$ - No. $i$ comparison sequence;

$n$ - Layer numbers of production split.

3.3.2. Correlation coefficient calculation

According to the model of Deng’s correlation degree, after the original data has been dimensionless, the absolute difference between the values of No. $i$ comparison sequence samples and the values of corresponding reference sequence samples is expressed as:

$$A_{oi} (k) = |X_o (k) - X_i (k)| \quad (9)$$

The maximum and minimum values of absolute difference among the sample data in all the comparison sequences are expressed as:

$$\Delta_{max} = \max_{i=1,2,...,m} \max_{k=1,2,...,n} (A_{oi} (k)) \quad (10)$$

$$\Delta_{min} = \min_{i=1,2,...,m} \min_{k=1,2,...,n} (A_{oi} (k)) \quad (11)$$

The Deng’s correlation coefficient of No. $i$ comparison sequence compared with reference sequence in the No. $k$ sample is expressed as:

$$\xi_{oi} (k) = \frac{\Delta_{min} + \rho \Delta_{max}}{\Delta_{oi} (k) + \rho \Delta_{max}} \quad (12)$$

In the above formula:

$\rho$ - Resolution coefficient, $\rho \in (0,1)$.

The resolution coefficient function is improving the difference significance between the correlation coefficients. The smaller $\rho$ value increases the difference significantly between the correlation coefficients. A satisfactory resolution coefficient is usually obtained by taking 0.5.

3.3.3. Correlation degree calculation

The information reflected by a single correlation coefficient is dispersed. And the correlation degree between the comparison sequence and the reference sequence is simply represented by $n$ numbers of correlation coefficients, which can’t reflect the influence of dynamic and static factors on the production split. The correlation information is processed centrally, and the correlation degree between the sequences is quantitatively reflected by the mean value of the correlation coefficients.

$$r_{oi} = \frac{1}{n} \sum_{k=1}^{n} \xi_{oi} (k) \quad (13)$$

$r_{oi}$ is the correlation degree between $r_{oi} = \frac{1}{n} \sum_{k=1}^{n} \xi_{oi} (k)$ arison sequence and the reference sequence. The greater the correlation degree, the more accurate between the comparison sequence and the reference sequence. In the dynamic and static influence factors analysis of production split, we pay more attention to the relative magnitude of the two factors influence degree, namely the relative magnitude of the two comparison sequences correlation degree. The correlation degree is normalized and correlation degree weight ($D_i$) of two comparison sequences is expressed as:

$$D_i = \frac{r_{oi}}{\sum_{i=1}^{n} r_{oi}} \quad (14)$$
By using this method, the dynamic correlation degree weight \(D_g\) and static correlation degree weight \(D_e\) of the oil reservoir are determined by massive reservoir data calculation, \((D_g + D_e = 1)\). At this point, the No. \(i\) layer split coefficient \(C_i\) can be expressed as:

\[
C_i = D_g \cdot C_{gi} + D_e \cdot C_{ei}
\]  

(15)

In the above formula:
- \(C_i\) - No. \(i\) layer split coefficient, dimensionless;
- \(D_g\) - Static geologic factor correlation degree weight, dimensionless;
- \(C_{gi}\) - No. \(i\) layer static geologic factor weight, dimensionless;
- \(D_e\) - Dynamic development factor correlation degree weight, dimensionless;
- \(C_{ei}\) - No. \(i\) layer s dynamic development factor weight, dimensionless.

4. Method validation and application

The C30 fault block of Chaheji oilfield is taken as an example. The output of 15 production wells in the research block is split by using grey correlation degree production split method. Then the correlation degree weight \(D_i\) is obtained. The static geologic factor correlation degree weight and dynamic development factor correlation degree weight of C30 fault block are 0.428 and 0.572 respectively. The production split results are verified by the oil producing profile. And the split results are highly accurate, which completely satisfies the practical application of the field.

Taking the C30-136 well of the research block as an example. According to the above production split method, the grey correlation degree split result is compared with the test data of oil producing profile and the split result of the formation coefficient method (KH method), as shown in table 4 and figure 1. As can be seen from table 4 and figure 1, the split results of KH method are quite different from that of the oil production profile, which is due to the less consideration on reservoir property influence and water injection well influence. Grey correlation degree split method synthetically considers the influence weight of static geologic factors and dynamic development factors. Compared split result with oil producing profile data, which inaccuracy is minute. This indicates that using grey correlation degree split method to calculate the production split is reasonable.

| Layer | Oil producing profile \(10^4\) | KH method \(10^4\) | Grey correlation method \(10^4\) |
|-------|-----------------|-----------------|-------------------|
| III-12-1 | 0.512 | 0.259 | 0.530 |
| III-18-2 | 0.142 | 0.489 | 0.167 |
| IV-2-1 | 0.540 | 0.385 | 0.515 |
| IV-15-2 | 0.142 | 0.202 | 0.124 |
5. Conclusion

(1) The production split method based on grey relational analysis method fully considers the influence of static geologic factors weight and dynamic development factors weight. It is more reasonable than formation coefficient method (KH method). And its development condition is less limited than that of dynamic equation split method (Ci equation method).

(2) The calculation results of grey correlation degree production split method are more reliable, which can accurately grasp the status of the reservoir exploitation. The new production split method also provides powerful support for the study of the residual oil distribution and the development of oil field.

(3) The grey relational analysis method is combined with traditional production split methods, which is optimized for the oil reservoir production split method. It provides a new idea for the reservoir production split.

References

[1] FENG Xianyan, CHEN Xianxue. The method and application of individual wells production split [J]. Special Oil & Gas Reservoirs, 2009, 16(1):29-32.

[2] ZHENG Ailing, LIU Dehua, SHAO Yanling. Oil sand potential and development measures for complex fault-block reservoir[J]. Special Oil & Gas Reservoirs, 2011, 18(1):93-95.

[3] ZHAO Jin-cheng, ZHANG Shu-huan, QI Cheng-xiang. The methods of split and using these methods with an example[J]. Inner Mongolia Petrochemical Industry, 2010, 3:29-31.

[4] LI Junzhi. An improved split method of stratified liquid production[J]. Tuha Oil & Gas, 2008, 13(1):31-35.

[5] LI Ji, Luo Donghong, LIU Shuzhi, etal. The method of split on water injected volume and liquid produced capacity[J]. Inner Mongolia Petrochemical Industry, 2011(6):141-143.

[6] ASHEIM H. Maximization of water sweep efficiency by controlling production and injection rates [J]. Society of Petroleum Engineers, 1988, doi: 10, 2118 / 18365-MS.

[7] QIU Hong-bing. Evaluation of residual oil potentiality exploration of buried hill reservoir in Shu 13938 of Shuguang Oilfield [J]. Lithological hydrocarbon reservoir, 2010, 22(1):129-133.