The Application of Fuzzy Comprehensive Evaluation Method in Evaluating Remaining Oil Potential of Oil Layer

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Abstract. In this paper, remaining oil saturation, microfacies type, oil layer thickness, structure, permeability variation coefficient, injection-production relationship, injection-production perfection degree, effective perforation thickness, connected thickness, water injection distance, water injection well pattern, water cut of oil well and production measures, these thirteen static and production dynamic indicators constitute the evaluation factor set of remaining oil potential, hierarchy and statistical analysis of weight coefficients are carried out for each factor, taking block A as an example, the multi-level fuzzy comprehensive evaluation method is used to quantitatively evaluate the remaining oil potential of complex heterogeneous reservoir, so as to achieve the purpose of regional governance in accordance with size of remaining oil potential.

Keywords: fuzzy comprehensive evaluation; remaining oil potential; potential tapping measures.

1. Introduction
The evaluation of remaining oil potential is the key to comprehensively adjust potential tapping of well patterns in the later stage of oilfield development; targeted potential tapping measures can be taken only by making clear the specific location and quantity of the oil layer remaining oil in the high water cut stage. There are many and complex factors affecting the distribution of remaining oil potential, there are both geological factors and development factors, and the effect of each influencing factor on the formation of remaining oil is ambiguous, and it is often impossible to use deterministic quantitative mathematical relations for evaluation, here the multi-level fuzzy comprehensive evaluation method is used to consider 13 influencing factors such as the heterogeneous characteristics of oil layer and its development behaviors [1-3], taking block A as an example, the remaining oil potential of complex heterogeneous reservoir is quantitatively evaluated, the quantitative model of remaining oil potential analysis is established, and achieve the purpose of regional governance in accordance with the size of remaining oil potential.
2. Principles and Methods of Fuzzy Comprehensive Evaluation

2.1. Fuzzy comprehensive evaluation parameters

2.1.1. Geological evaluation parameters. The analysis of geological factors affecting the distribution of remaining oil potential shows that geological evaluation can be divided into the following five parameters, and each parameter is further subdivided in accordance with the size of remaining oil potential: (1) remaining oil saturation, (2) types of microfacies: underwater distributary channel, main thin layer sand, non-main thin layer sand and off-surface, (3) oil layer thickness, (4) structure: structural low point, structural high point, closed fault, (5) the permeability variation coefficient.

2.1.2. Development evaluation parameters. The analysis of development factors affecting the distribution of remaining oil potential shows that development evaluation can be divided into the following eight parameters, and each parameter is further subdivided in accordance with the size of remaining oil potential: (1) injection-production relationship: mainstream line, diversion line, retention area, (2) perfection degree of injection and production, (3) effective perforation thickness, (4) connected thickness, (5) water injection distance: ≤200m, 200~300m, ≥300m, (6) water injection well pattern: basic well pattern, one-time infilling, two-time infilling and three-time infilling, (7) water cut of oil well, (8) production measures: fracturing, acidification and water plugging, no measures.

2.2. Fuzzy comprehensive evaluation method

2.2.1. First-level fuzzy comprehensive evaluation. The first-level fuzzy comprehensive evaluation is to comprehensively evaluate each parameter of two major factors affecting the distribution of remaining oil potential in accordance with its impact on remaining oil potential in this class. First, according to the degree of remaining oil enrichment, the non-quantitative indicators such as microfacies type, structure, injection-production relationship, etc., are assigned 0.11, 0.33, and 0.56, respectively, the transformation from non-quantitative index to quantitative index is realized, and all parameters are normalized in accordance with layer and well, then the remaining oil potential is judged from geological factors and development factors two aspects, respectively, the set of geological factors Rgf=remaining oil saturation A, microfacies type B, oil layer thickness C, structure D, permeability variation coefficient E}, development factor set Rdf={injection-production relationship F, injection-production perfection degree G, effective perforation thickness H, connected thickness I, water injection distance J, water injection well pattern K, water cut of oil well L, production measures M}, the evaluation fuzzy relationship matrix of geological factors and development factors is established.

In addition, since each parameter in geological factors and development factors has different impact on the distribution of remaining oil potential, the weights of five parameters of geological factors and eight parameters of development factors are assigned to reflect this difference, the method which combines expert scoring and factor analysis is adopted to determine the weight coefficient, they are recorded as Agf={A, B, C, D, E }={0.3, 0.2, 0.2, 0.2, 0.1}, Adf={F, G, H, I, J, K, L, M}= {0.2, 0.2, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1}, respectively, the weighting coefficient matrix and the fuzzy relation matrix are combined into B=A•R, the result matrices Bgf and Bdf of the fuzzy comprehensive evaluation of geological factors and development factors are obtained, respectively.

2.2.2. Second-level fuzzy comprehensive evaluation. Since the distribution of remaining oil potential is the outcome of the comprehensive action of geological factors and development factors, the second-level comprehensive evaluation is required on the basis of the first-level comprehensive evaluation of geological factors and development factors. The factor set of the second-level comprehensive evaluation R= (geological factors, development factors), the weighing coefficient matrix C=\((0.5, 0.5)\), the weighting coefficient matrix and the fuzzy relationship matrix are combined into D= C•R, finally, the comprehensive evaluation result D of the remaining oil potential is obtained. According to the
comprehensive evaluation result $D$, the remaining oil potential is divided into 4 classes: $D \geq 0.5$ is the excellent remaining oil potential area; $0.45 \leq D < 0.5$ is the good remaining oil potential area; $0.4 < D < 0.45$ is the intermediate remaining oil potential area; $D \leq 0.4$ is the poor remaining oil potential area.

3. Application Examples

3.1. Division of remaining oil potential
Taking well A21 in block A as an example, and the specific parameters are shown in Table.1.

| parameter                        | content | development factors | parameter                        | content               |
|----------------------------------|---------|---------------------|----------------------------------|-----------------------|
| remaining oil saturation         | 0.46    | injection-          | injection-production relationship| main stream line      |
| microfacies type                 | 83.46   | production          | degree                           | 4                     |
| oil layer thickness              | 112.6   | effective           | perforation thickness            | 5.7                   |
| structure                        | structural low position | Connected thickness | 79.1                              |
| permeability variation coefficient | 0.84    | water injection      | distance                         | 185                   |
|                                  |         | well pattern        | secondary infilling              |                       |
|                                  |         | water cut of oil    | well                             | 0.92                  |
|                                  |         | measures            | fracture                         |                       |

After normalization, the evaluation fuzzy relationship matrices of geological factors and development factors are as follows:

$$
R_{Gf} = \begin{bmatrix}
0.46 \\
0.94 \\
0.72 \\
0.11 \\
0.37
\end{bmatrix}, \quad R_{Df} = \begin{bmatrix}
0.11 \\
1.00 \\
0.12 \\
0.72 \\
0.11 \\
0.56 \\
0.08 \\
0.11
\end{bmatrix}
$$

The weights of five parameters in the geological factors $A_{Gf} = \{0.3, 0.2, 0.2, 0.2, 0.1\}$, the weights of the eight parameters in the development factors $A_{Df} = \{0.2, 0.2, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1\}$, the weighting coefficient matrix and the fuzzy relationship matrix are combined into $B = A \cdot R$, and the result matrices $B_{Gf} = 0.53, B_{Df} = 0.39$ of fuzzy comprehensive evaluation of geological factors and development factors are obtained, respectively. On the basis of the first-level comprehensive evaluation of geological factors and development factors, the second-level comprehensive evaluation is carried out. The factor set of the secondary comprehensive evaluation is $R = \begin{bmatrix}
0.53 \\
0.39
\end{bmatrix}$, the weighting coefficient matrix $C = \{0.5, 0.5\}$, the weighting coefficient matrix and the fuzzy relationship matrix are combined into $D = C \cdot R$, and finally the comprehensive evaluation result $D = 0.46$ of remaining oil potential is obtained, it belongs to good remaining oil potential area. The distribution of remaining oil potential in the whole area is shown in Fig.1.

![Fig. 1 Distribution of remaining oil potential in the whole area](image-url)
3.2. Potential tapping direction

1) Class I potential zone: this potential zone is mainly located at structural high point, the sand body is well developed, the oil-bearing thickness is large, the remaining oil saturation is low, and the injection-production relationship is relatively complete, but the permeability variation coefficient is greater than 1, heterogeneity among layers is strong, considering that most of the wells in this type of area are unmeasured wells, fracturing measures can be taken in the next step to transform the low-permeability layers, reduce the difference among layers, and improve the use state of the oil layer.

2) Class II potential area: this potential area has good sand body development, larger oil-bearing thickness, higher remaining oil saturation, and better injection-production perfection degree, considering that some wells in this type of area are located near the fault, comparing them with other wells in this type of area, the water injection distance is longer, the injection-production relationship is poor, the injection-production perfection degree is lower, and the connected thickness is smaller, the next step is mainly to improve the injection-production relationship, and tap the remaining oil near the fault.

3) Class III potential area: this potential area has good sand body development, large oil-bearing thickness, high remaining oil saturation, and good injection-production perfection, but the effective perforation thickness of oil well is small, only 6.93m, the next step can take measures to fill the hole, improve the perfection degree of oil layer, and further tap the remaining oil in the hole layer.

4) Class IV potential zone: This potential zone is mainly located in the low position of the structure, the edge of the oil sand body, the oil-bearing thickness is small, the remaining oil saturation is low, the water injection distance is greater than 300m, the injection-production perfection degree is less than 2, and the connected thickness is only 10m, the injection-production relationship is poor, the next step can combine infilling wells and hole-filling measures, on the one hand, reduce the water injection distance and increase the effective direction of the oil well, and on the other hand, increase the connected thickness of the surrounding water wells.

4. Conclusion

The factors that affect distributed geology of remaining oil potential and development dynamic are extremely complex, and different factors have different levels of structure and impact, various influencing factors are classified into 13 classes in the research, hierarchy and statistical analysis of weight coefficients are conducted for each class of factor, on this basis, multi-level fuzzy comprehensive evaluation technology is introduced, taking block A as an example, quantitative evaluation is carried out for the remaining oil potential of complex heterogeneous reservoirs, the quantitative model of remaining oil potential analysis is established, and achieve the purpose of regional governance in accordance with the size of remaining oil potential.

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