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# Application of fuzzy clustering analysis in Classification of dominant channel of steam flooding: A case study of S121 Layer, Member 1 of Shawan Formation, Block P612, CF Oilfield

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**Abstract:** In order to determine the dominant channel of steam flooding in heavy oil reservoir P612 block of CF oilfield, the geological evaluation parameters of five dominant channels of steam flooding, namely permeability, reservoir thickness, sedimentary microfacies, coefficient of variation and interlayer frequency, were determined by combining reservoir static description with development dynamic analysis. According to the development dynamic characteristics, the sand body of the dominant channel was determined and the sample data was extracted. The fuzzy clustering analysis method was used to divide the two categories of the dominant channel and determine the interval value of its parameters. Thus, the geological classification evaluation standard of the dominant channel was established.

**Keyword:** CF oil field; Heavy oil reservoir; Steam drive superior channel; Fuzzy clustering.

## 1. Introduction

Steam flooding dominant channel is a kind of dominant seepage channel formed under the influence of a series of factors such as geology and development. From the perspective of development, it means that due to the influence of reservoir heterogeneity, the steam absorption capacity of high and low permeability layer is different in the longitudinal direction, so that the injected steam is easy to burst along the high permeability layer with low seepage resistance and the high part of the structure updip, forming the steam flooding dominant channel[1].

In this paper, by dissecting the first member of Shawan Formation P612 steam flooding development block, the identification marks and main controlling factors of steam flooding superior channels in heavy oil reservoirs were discussed, multi-parameter evaluation criteria were established, and fuzzy clustering analysis method was applied to comprehensively and quantitatively classify steam flooding superior channels, providing a basis for the formulation of heavy oil reservoir production and development program.

## 2. Geological overview of the study area

CF oil field is located in the town of Wateraba, Qianshan, Karamay City, Xinjiang Uygur Autonomous Region, about 70km away from Karamay City[4].The structure is located in the northeast of Chepaizi uplift (Figure 1). The main oil-bearing reservoir is the first member of Neogene Shawan Formation, which is characterized by high crude viscosity, shallow burial, thin thickness, low formation temperature, and insufficient natural energy. In 2012, proved reserves of 13,834,200 tons were reported. The production capacity of this block was established in 2012, and the production was fully started in June 2015. At present, there have been 15 ~ 16 production cycles, and the reservoir pressure is 1.0 ~ 1.2MPa.

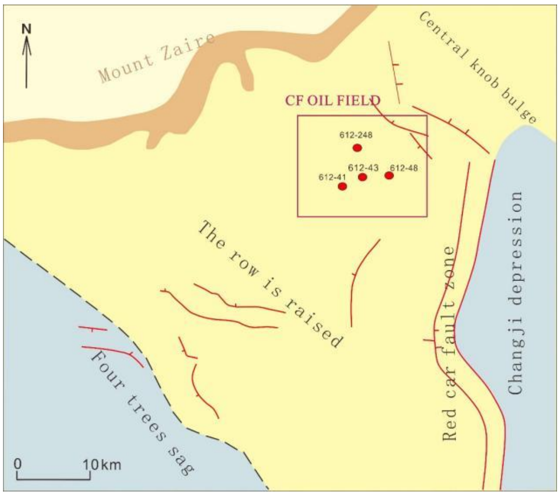


**Figure 1.** Regional Structure map of CF Oilfield (modified from Song Fan 2013)

## 3. Selection of evaluation parameters of the dominant channel

### 3.1. Reservoir physical properties

Permeability and porosity are important factors to judge the existence of the dominant channel in the reservoir physical property. The better the reservoir physical property is, the easier it is to form the dominant channel of steam drive. Among the reservoir physical parameters, permeability has a good correlation with the development effect of heavy oil. Generally speaking, the porosity can reflect the permeability level. In the linear coordinate system, the relationship diagram between permeability and porosity is made, and it can be seen that there is a good correlation between permeability and porosity (Figure 2).

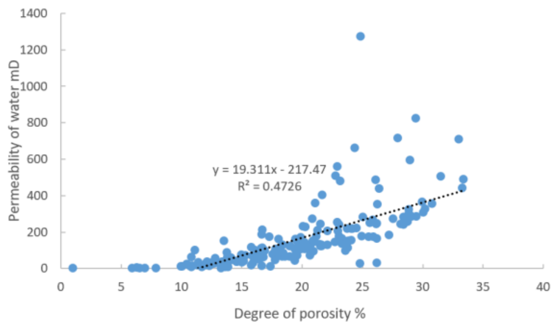


**Figure 2.** Relationship between porosity and permeability

## 3.2. Sedimentary microfacies

The influence of different sedimentary microfacies and their combination on the development of heavy oil thermal recovery is mainly manifested in three aspects: affecting the degree of reserve utilization; It affects the formation pressure drop rate of fault block. It will affect the quality of gas injection and cause great heat loss, sand production and pollution. The study area is located in the main part of the fan delta front and braided river delta front subfacies. According to the sedimentary environment and facies signature characteristics, the core well sedimentary sequence combination, combined with the petroelectric characteristics, can be divided into four kinds of sedimentary microfacies: underwater distributary channel, interbranch bay, core beach and muddy channel. Through the interpretation of steam channeling channel and the verification of the production and suction profile, most of the gas channeling channel develops in the sand body of underwater distributary channel with good physical properties, and it is easiest to form steam channeling channel at the top of the beach bar with good physical properties or at the bottom of the underwater distributary channel. In Figure 3, steam channeling occurs in the 612-43 production well and steam injection well group located on the underwater distributary channel, forming the dominant channel of steam flooding.

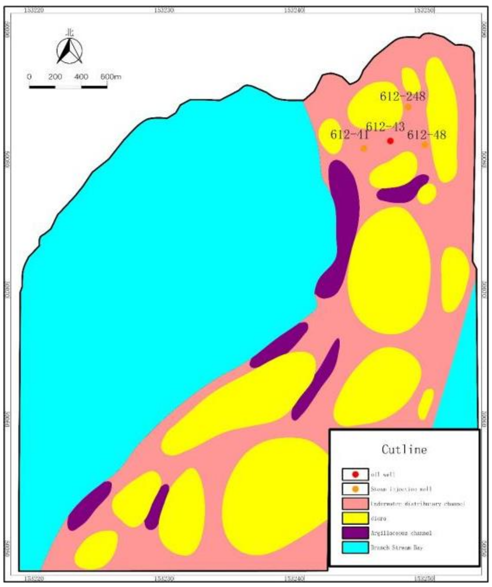


**Figure 3.** Sedimentary microfacies plan of S121 layer

## 3.3. Reservoir thickness

The oil reservoir is the material foundation of steam flooding development, and the thickness of oil reservoir includes the thickness of sandstone and thin mud rock, which is an important factor affecting the steam flooding exploitation of heavy oil.The influence of oil layer thickness on steam flooding effect is mainly the heat loss of overlying strata and underlying strata. When the oil layer is thinner, the heat loss ratio of the topside layer and the bottom layer increases, and the heat utilization efficiency is poor, and the oil flooding effect is poor; When the oil layer thickness increases gradually, the reserves controlled by a single well increase, the heat loss ratio to cap layer and bottom layer decreases, the oil production of a single well is high, and the steam flooding effect and economic benefits gradually become better. However, when the oil layer thickness is too large, the steam utilization efficiency deteriorates due to the gravity separation of steam and water in the wellbore and the aggravation of steam overburden in the oil layer. Resulting in lower oil displacement effect.

Generally, the thicker the reservoir, the larger the net gross ratio, the smaller the heat loss. The effective thickness of the reservoir is too small, even if the permeability of the reservoir is high, it is difficult to form an effective steam channeling advantageous channel. The research shows that with the increase of effective thickness, the development effect of steam flooding well group becomes better gradually. But when the effective thickness is thicker, it is easy to cause steam channeling.

## 3.4. Reservoir heterogeneity

Due to the influence of reservoir heterogeneity, the steam absorption capacity of high and low permeability reservoirs is different in the longitudinal direction, so that the injected steam is easy to burst along the high permeability layer with low seepage resistance, forming the steam flooding channel. The reservoir heterogeneity mainly includes plane, intra - layer and interlayer heterogeneity. The interzonal heterogeneity determines the longitudinal application degree of a single well. Where the permeability variation coefficient is high, the application degree is high (Figure 4), and the 612-43 production well - steam injection well group is easy to form the dominant channel of steam flooding.

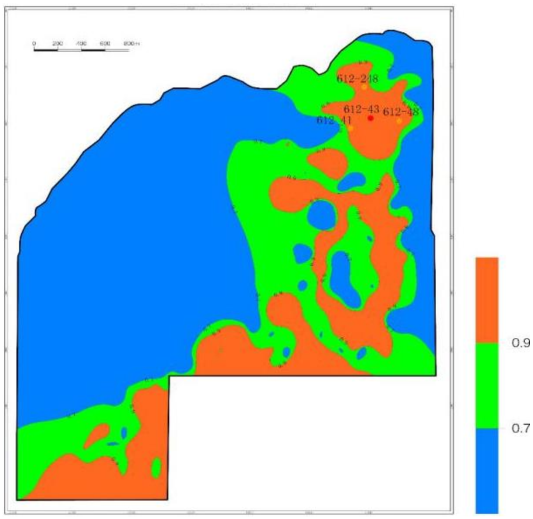


**Figure4.** Floor plan of permeability variation coefficient of S121 layer

## 3.5. Features of interlayer

The development of interlayer will affect the thermal utilization of steam. From the characteristics of interlayer in the main microphases, the interlayer in the branch bay is the thickest, followed by the channel edge, and the channel interlayer is the thinnest. From the comparison between the development effect and the interlayer frequency, the development effect of the production well and steam injection well group in the area with high interlayer frequency is poor, and the dominant channel of steam flooding is easily generated (Figure 5).

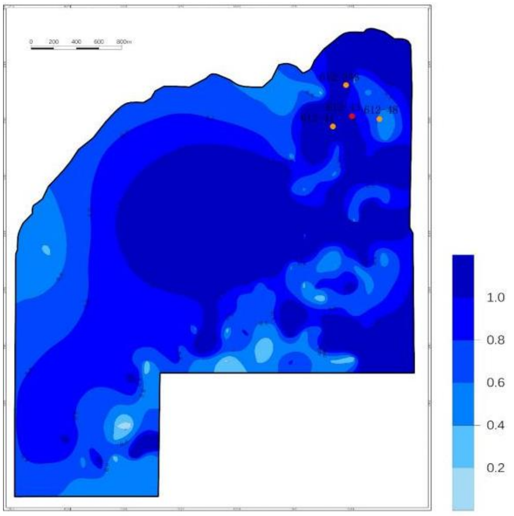


**Figure 5.** Interlayer frequency plan of S121

# 4. Fuzzy cluster analysis of dominant channel comprehensive classification

System clustering is a fuzzy clustering analysis method based on fuzzy equivalence relation, while stepwise clustering is a fuzzy clustering analysis method based on fuzzy partition. This study adopts stepwise clustering method.

## 4.1. Basic idea of fuzzy cluster analysis

The basic principle of fuzzy clustering is as follows: set n samples, each sample Xi , There are m characteristic indexes, then the characteristic index matrix of n samples is $X=[x_{ij}]_{n\times m}$ (all xij data have been normalized)。The sample space X was calibrated to establish the fuzzy similarity relation matrix:

$$R=[r_{ij}]_{n\times n},\quad 0\leqslant r_{ij}\leqslant 1 \qquad (1)$$

The matrix is a fuzzy similarity matrix, the determination of rij mainly uses the traditional clustering similarity coefficient method, distance method and other methods. The fuzzy transitive closure of R is constructed by using the square autosynthesis method:

$$R^*=R^2 \qquad (2)$$

## 4.2. Steps of fuzzy cluster analysis

### 4.2.1. Data Matrix

Let the domain U={X1,X2,…,Xn} is the classified object, and each object has m indicators to represent its character, namely:

$$x_i=\{x_{i1},x_{i2},\cdots,x_{im}\}\quad (i=1,2,\cdots,n) \qquad (3)$$

Thus, the original matrix is:

$$X=\begin{pmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{pmatrix} \qquad (4)$$

### 4.2.2. Data standardization

In practical problems, different data generally have different dimensions, in order to make different dimensions can be compared, usually need to do the appropriate transformation of the data.The main transformation methods are: translation standard deviation transformation, translation range transformation and logarithmic transformation. However, even then, the resulting data may not be in the interval [0,1]. Therefore, the data standardization mentioned here is to compress the data into the interval of [0,1] according to the requirements of fuzzy matrix.

$$x_i'=\frac{x_i-x_{i\min}}{x_{i\max}-x_{i\min}}\quad (i=1,2,\cdots,m) \qquad (5)$$

### 4.2.3. Fuzzy similarity matrix is established

Let the domain U={X1,X2,...,Xn}, xi={xi1,xi2,...xim}, according to the traditional clustering method to determine the similarity coefficient, establish the fuzzy similarity matrix, the degree of similarity between xi and xj is rij=R(xi, xj).Determine rij=R(xi, xj) is mainly based on the maximum and minimum method of stepwise clustering.

$$r_{ij}=\frac{\sum_{k=1}^{m}(x_{ik}\wedge x_{jk})}{\sum_{k=1}^{m}(x_{ik}\vee x_{jk})}\quad (x_{ij}>0, i=1,2,\cdots,n, j=1,2,\cdots,m) \qquad (6)$$

When rij=0, it means that sample xi is not similar to sample xj. When rij=1, sample xi and sample xj are exactly the same or equivalent; When rij is the sample, the degree of similarity between xi and itself is always 1, and then a fuzzy similarity relation matrix between samples is obtained.

$$R=\begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nn} \end{bmatrix} \qquad (7)$$

### 4.2.4. Cluster analysis

Using the transfer closure method, the fuzzy matrix R obtained from the calibration is transformed into the fuzzy equivalent matrix R*.Find the transitive closure of R by the quadratic method, that is, t(R) = R*.Then λ∈(0,1) from large to small, determine the corresponding λ section matrix, it can be classified, and can form a dynamic cluster graph.

# 5. Classification of dominant channels based on fuzzy clustering

According to the dynamic data of the dominant channel of steam flooding, the sand layer developed in the dominant channel of steam flooding was determined. A total of 94 sample data of 5 geological parameters, such as permeability, reservoir thickness, sedimentary microfacies, coefficient of variation and interlayer frequency, were extracted, and the sand body of the main target layer in the study area was accurately evaluated by single well. Descriptive parameters were quantified by assignment coding, and dimensionless and normalized processing was carried out by Min-max standardization (Table 1).

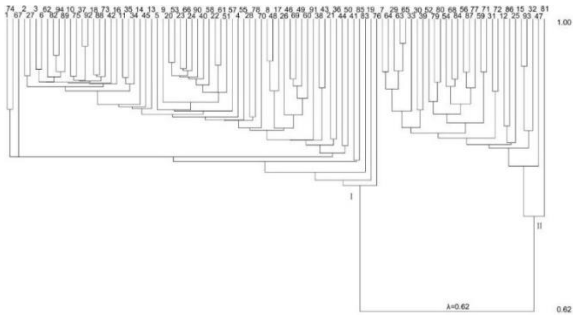


**Figure 6.** Cluster analysis diagram

Then, according to the sample classification results, the standard values of the dominant channel parameters of each kind of steam drive can be obtained respectively. A fuzzy equivalent matrix can determine a fuzzy classification. Therefore, different threshold λ can be selected for dynamic clustering analysis of R*, and the following clustering diagram is generated (Figure 6).

**Table 1.** Sand layer parameter statistics of partial steam drive dominant channel

| The serial | Measured data | | | | | Standardized data | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Permeability of water | Reservoir thickness | Microfacies of deposition | Coefficient of variation | Frequency of interlayer | Permeability of water | Reservoir thickness | Microfacies of deposition | Coefficient of variation | Frequency of interlayer |
| 1 | 438.3 | 6.98 | river | 0.680 | 0.446 | 0.287 | 0.49 | 0 | 0.350 | 0.125 |
| 2 | 176.9 | 6.9 | river | 0.918 | 1.111 | 0.064 | 0.48 | 0 | 0.518 | 0.383 |
| 3 | 176.7 | 7.5 | river | 0.857 | 1.428 | 0.064 | 0.54 | 0 | 0.475 | 0.506 |
| 4 | 100.8 | 7.7 | river | 1.536 | 1.176 | 0 | 0.56 | 0 | 0.956 | 0.408 |
| 5 | 250.6 | 7.7 | river | 0.750 | 0.312 | 0.127 | 0.56 | 0 | 0.399 | 0.073 |
| 6 | 149.1 | 7.3 | river | 0.728 | 1.428 | 0.041 | 0.52 | 0 | 0.383 | 0.506 |
| 7 | 130.2 | 8.2 | edge | 0.976 | 0.952 | 0.025 | 0.61 | 1 | 0.559 | 0.321 |
| 8 | 153.1 | 8.4 | river | 0.615 | 0.800 | 0.044 | 0.63 | 0 | 0.303 | 0.262 |
| 9 | 129.5 | 6.6 | river | 0.863 | 0.400 | 0.024 | 0.45 | 0 | 0.479 | 0.107 |
| 1 | 148.9 | 7.7 | river | 1.025 | 1.333 | 0.041 | 0.56 | 0 | 0.594 | 0.469 |
| ... | | | | | | | | | | |
| 8 | 363.4 | 10.2 | river | 0.726 | 1.005 | 0.223 | 0.81 | 0 | 0.382 | 0.342 |
| 8 | 289.9 | 5.73 | edge | 0.252 | 1.190 | 0.161 | 0.36 | 1 | 0.046 | 0.413 |
| 8 | 108.7 | 2.64 | edge | 0.703 | 0.689 | 0.006 | 0.06 | 1 | 0.366 | 0.219 |
| 8 | 160.7 | 9.46 | river | 0.991 | 1.020 | 0.051 | 0.74 | 0 | 0.569 | 0.348 |
| 8 | 219.3 | 9.14 | river | 0.847 | 1.680 | 0.101 | 0.71 | 0 | 0.468 | 0.603 |
| 9 | 186.4 | 7.44 | river | 0.989 | 0.361 | 0.073 | 0.54 | 0 | 0.568 | 0.092 |
| 9 | 486.7 | 7.51 | river | 0.940 | 1.260 | 0.329 | 0.54 | 0 | 0.533 | 0.441 |
| 9 | 254.2 | 8.03 | river | 1.137 | 1.739 | 0.130 | 0.59 | 0 | 0.673 | 0.626 |
| 9 | 107.2 | 2.43 | edge | 0.883 | 2.702 | 0.005 | 0.03 | 1 | 0.494 | 1 |
| 9 | 243.1 | 9.44 | river | 0.980 | 1.562 | 0.121 | 0.74 | 0 | 0.562 | 0.558 |

**Table 2.** Evaluation criteria for dominant channels

| Type | Number of samples | Permeability (mD) | Reservoir thickness (m) | Microfacies of deposition | Coefficient of variation | Interlayer frequency (bar /m) |
|---|---|---|---|---|---|---|
| Class I vapor drive advantage channel | 65 | 100.813-1273.945(247.423) | 4.47-12.03(8.09) | river | 0.325-1.537(0.875) | 0.122-2.256(0.988) |
| Class II vapor drive advantage channel | 29 | 107.296-661.083(220.166) | 2.04-8.58(4.86) | edge | 0.186-1.598(0.797) | 0.337-2.703(1.027) |

When λ=0.62, the 94-sample data are divided into two categories, and the average value of the sample index is obtained respectively, which is taken as the characteristic parameter value of the steam drive superior channel. Thus, two categories of the steam drive superior channel types are divided and the fuzzy evaluation standard of the steam drive superior channel is established, which can be applied to the pattern recognition of the steam drive superior channel: The dominant channel of Class I is the main development type, channel microfacies sedimentary sand body, average reservoir thickness of 8.09 m, average permeability of 247.423mD, average coefficient of variation of 0.875, average interlayer frequency of 0.988 /m. The dominant channel of Class II steam flooding is channel edge microfacies sandstone with an average reservoir thickness of 4.86m, an average permeability of 220.166mD, an average coefficient of variation of 0.797, and an average interlayer frequency of 1.027 /m (Table 2).

# 6. Conclusion

(1) The main geological influencing factors of the steam drive channel include the sedimentary characteristics of sand bodies, reservoir physical properties, reservoir heterogeneity and structural characteristics, etc. Permeability, sedimentary microfacies, reservoir thickness, coefficient of variation and interlayer frequency can be selected as the geological evaluation parameters.

(2) Based on the dynamic development data, the dominant channel of steam drive is identified and the sample data is extracted. The fuzzy clustering analysis method is used to carry out the sand-layer comprehensive evaluation of the dominant channel of steam drive, which can objectively classify the dominant channel types of steam drive and establish the fuzzy evaluation standard.

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