Study on Reservoir Heterogeneity of Putaohua Oil Layer in Gulongnan Area

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Abstract. Putaohua oil layer is the main target layer in gulongnan area. The reservoir is mainly sheet sand with thin thickness, heavy mud content and poor physical properties. In recent years, the development effect of different blocks in this area is quite different. In this paper, the reservoir heterogeneity in Gulongnan area and each block is studied to provide reliable geological basis for improving oilfield development effect. Through the analysis of intra-layer, inter-layer and plane heterogeneity, it is considered that the overall reservoir heterogeneity in Gulongnan area is strong. In terms of deposition units, the heterogeneity of PI1, PI3 and PI6 is relatively strong, while the heterogeneity of PI2 and PI7 is relatively weak, and the remaining units are in between. In terms of zoning, the heterogeneity in G6 block is weak, the heterogeneity in M1 and A1 blocks is strong, and the heterogeneity in D1 block is the strongest. The application of heterogeneity analysis results provides strong support for promoting oil well effectiveness and delaying water breakthrough time.

Keywords: Gu Longnan; Putaohua oil layer; Heterogeneity.

1. Introduction
Gulongnan area is located in the south of Qijia-Gulong Sag, where Putaohua oil layer is developed. The sand body is mainly sheet sand with thin thickness, heavy mud content and poor physical properties. In recent years, the horizontal-vertical combined well pattern has been used for development, although certain results have been achieved, but the development effects of different well areas are quite different. To realize the rational development of the block, it is necessary to master the characteristics of reservoir heterogeneity [1]. Reservoir heterogeneity is an important basic content in basic geological research, which plays a guiding role in oil and gas field exploration and development [2]. Especially for the oilfield in the later stage of exploitation, in order to realize efficient oilfield exploitation, fine reservoir description should be carried out comprehensively, and in-depth study on heterogeneity is needed [3, 4]. Because the quality of reservoir directly affects the productivity, water injection effect and recovery ratio of oil layer, the study of reservoir heterogeneity in Gulongnan area provides a basis for better improving the production effect and tapping potential [5].
2. Study on Reservoir Heterogeneity

Reservoir heterogeneity is one of the core contents of reservoir description, which refers to the spatial heterogeneity of reservoir parameters, including the heterogeneity of lithology, electrical property, physical property, oil-bearing property and micro-pore structure in three-dimensional space, which is a common characteristic of reservoirs and is mainly affected by sedimentary environment, diageneis and structural factors [4, 6-13]. There are many types of reservoir heterogeneity. At present, the classification method of Qiu Yinan (1997) is applied by Guangfa in China's major oilfields, and clastic reservoir heterogeneity is divided into four categories: microscopic heterogeneity, intralayer heterogeneity, interlayer heterogeneity and planar heterogeneity [2, 4 and 7]. In this paper, the study of reservoir heterogeneity mainly uses logging interpretation results to analyze the characteristics of intra-layer heterogeneity, inter-layer heterogeneity and plane heterogeneity of reservoir groups in each block of the study area.

2.1. Evaluation parameters and evaluation criteria of heterogeneity

There are many parameters to characterize reservoir heterogeneity. Permeability variation coefficient, penetration coefficient and grade difference are often used to characterize reservoir heterogeneity and comprehensively evaluate reservoir heterogeneity [4, 7].

(1) variation coefficient of permeability (\( V_k \))

Refers to the ratio of permeability standard deviation to average value, i.e.:

\[
V_k = \frac{\sigma}{k}
\]  \( (1) \)

Among them:

\[
\sigma = \left( \sum_{i=1}^{n} (k_i - \bar{k})^2 / (n-1) \right)^{1/2}
\]  \( (2) \)

\[
\bar{k} = \frac{1}{n} \sum_{i=1}^{n} k_i
\]  \( (3) \)

Where \( n \) is the total number of sampling points in the layer.

Coefficient of variation reflects the degree of deviation of the sample from the overall average. The variation range is \( V_k \geq 0 \), and the smaller the value, the more uniform the sample value. On the contrary, the stronger the heterogeneity is, the more homogeneous it is when \( V_k = 0 \).

(2) Penetration coefficient (\( S_k \))

The ratio of maximum permeability (\( K_{max} \)) to average permeability (\( \bar{K} \)) in a certain interval. That is:

\[
S_k = \frac{K_{max}}{\bar{K}}
\]  \( (4) \)

The variation range is \( S_k \geq 1 \), and the smaller the value, the smaller the change of vertical permeability, the larger swept volume of injectant and the better oil displacement effect. The larger the numerical value, the larger the permeability changes in the vertical direction, and the injectant is easy to enter from the high permeability section, the swept volume of the injectant is small, and the water flooding effect is poor.

(3) Permeability ratio (\( N_k \))
Ratio of maximum permeability to minimum permeability in a certain interval. That is,

\[ N_k = \frac{K_{\text{max}}}{K_{\text{min}}} \]  

The parameter reflecting the change range of permeability is the difference degree of absolute value of permeability. The variation range is \( N_k \geq 1 \). The larger the value, the stronger the heterogeneity, and the closer the value is to 1, the more homogeneous the reservoir is.

2.2. Intralayer heterogeneity characteristics

The inhomogeneity in the layer shows the vertical permeability rhythm in the sand layer, the position of the highest permeable layer and the degree of heterogeneity, etc. [2, 11-13]. The inhomogeneity in a single sand layer directly controls and influences the vertical sweep thickness of injectant.

(1) Intralayer prosodic features

The core and logging data in Gulongnan area show that the permeability and grain size in a single sand body have various rhythmic characteristics, and the heterogeneity in the reservoir layer changes regularly under their control. Rhythm formed by vertical changes of sand bodies mainly includes two modes: positive rhythm and anti-rhythm.

① Positive rhythm

Positive rhythm is the main rhythm type of reservoir in the study area, and the highest permeability section is located at the bottom of sand body, and gradually decreases upward. The microfacies of underwater distributary channel are mainly rhythmic, and the curves of spontaneous potential and natural gamma ray are bell-shaped (Figure 1).

② Anti-rhythm

The highest permeability section of anti-rhythm is located at the top of sand body, which is mainly due to the decline of datum level, and the coarse-grained sediments deposited in the later period are deposited on the fine-grained sediments deposited in the early period, forming anti-rhythm. In the study area, there are some estuaries with anti-rhythm, and the spontaneous potential and natural gamma curve are box-shaped or funnel-shaped (Figure 2).
(2) Degree of heterogeneity of permeability in layers
Permeability change in layers is an important content to quantitatively describe heterogeneity in layers, which is generally characterized by permeability variation coefficient, permeability ratio and permeability surge coefficient. In order to further study the heterogeneity characteristics in each sublayer in Gulongnan area and each block, the permeability variation coefficient, penetration coefficient and level difference in each sublayer in the study area were calculated by using the single-point permeability value of logging interpretation results (Figure 3~ Figure 5). It can be seen from the figure that overall, the study area has strong heterogeneity. Among them, PI1, PI3 and PI6 have strong heterogeneity, PI2 and PI7 have weak heterogeneity, and the rest of the units in between. According to the zoning blocks, the heterogeneity in G6 block is weak, the heterogeneity in M1 and A1 blocks is strong, and the heterogeneity in D1 block is the strongest. It can be seen that, along the provenance direction, the heterogeneity in blocks G6 and M1 to A1 gradually increases, while the heterogeneity in block D1 is the strongest due to the influence of dual provenances.

Figure 3. Vertical distribution of coefficient of variation
Figure 4. Vertical distribution map of penetration coefficient

Figure 5. Vertical distribution diagram of grade difference
2.3. Interlayer heterogeneity

Interlayer heterogeneity refers to the vertical differences in lithology, physical properties and oil-bearing property among sand bodies in a certain unit, including cyclicity, heterogeneity of permeability and interlayer distribution, etc. It is the internal cause of interlayer interference, single-layer outburst and macroscopic remaining oil distribution [2, 14, 15]. In the oilfield developed by water injection, in-depth study of interlayer heterogeneity can provide reliable basis for major strategies such as adjustment of development strata and production technology of layered series.

(1) Degree of heterogeneity of interlayer permeability

According to the statistics of stratification coefficient and sand layer density of each block, the heterogeneity between reservoirs in G6 block is the strongest, the heterogeneity between reservoirs in A1 block is the weakest, and the heterogeneity between reservoirs in M1 block and D1 block lies between them (Table 1 and Table 2).

Table 1. Statistical table of stratification coefficient of each block in Gulongnan area

| Blocks   | PI1-1 | PI1-2 | PI2 | PI3 | PI4-1 | PI4-2 | PI5 | PI6 | PI7 | PI8 | Total |
|----------|-------|-------|-----|-----|-------|-------|-----|-----|-----|-----|--------|
| The whole region | 0.59  | 0.65  | 0.47 | 0.86 | 0.46  | 0.72  | 0.40 | 0.17 | 0.07 | 0.01 | 0.44  |
| G6       | 0.57  | 0.73  | 0.78 | 0.97 | 0.48  | 0.74  | 0.53 | 0.25 | 0.14 | 0.03 | 0.52  |
| M1       | 0.42  | 0.66  | 0.16 | 1.00 | 0.51  | 0.77  | 0.40 | 0.13 | 0.02 | 0.00 | 0.41  |
| D1       | 0.90  | 0.70  | 0.23 | 0.75 | 0.60  | 0.73  | 0.85 | 0.10 | 0.05 | 0.03 | 0.49  |
| A1       | 0.70  | 0.51  | 0.49 | 0.52 | 0.32  | 0.64  | 0.02 | 0.14 | 0.04 | 0.00 | 0.34  |

Table 2. Statistical table of sand layer density of each block in Gulongnan area

| Blocks   | PI1-1 | PI1-2 | PI2 | PI3 | PI4-1 | PI4-2 | PI5 | PI6 | PI7 | PI8 | Total |
|----------|-------|-------|-----|-----|-------|-------|-----|-----|-----|-----|--------|
| The whole region | 0.22  | 0.28  | 0.12 | 0.27 | 0.14  | 0.27  | 0.10 | 0.04 | 0.01 | 0.00 | 0.15  |
| G6       | 0.22  | 0.31  | 0.20 | 0.31 | 0.14  | 0.29  | 0.12 | 0.06 | 0.02 | 0.00 | 0.17  |
| M1       | 0.17  | 0.24  | 0.04 | 0.35 | 0.13  | 0.28  | 0.09 | 0.03 | 0.00 | 0.00 | 0.13  |
| D1       | 0.34  | 0.28  | 0.05 | 0.20 | 0.23  | 0.21  | 0.29 | 0.02 | 0.00 | 0.00 | 0.16  |
| A1       | 0.25  | 0.27  | 0.13 | 0.15 | 0.11  | 0.26  | 0.01 | 0.03 | 0.01 | 0.00 | 0.12  |

(2) Distribution characteristics of interlayer

The thickness of the interval layer of each small layer in the whole area is calculated (Table 2~Table 7). From the average thickness of the interval between each small layer in each block, the middle-upper sandstone group (PI1~PI5 small layer) The thickness of the interlayer is thin, and the thickness of the interlayer in the lower sandstone group (PI6~PI8) is large. In order to analyze the characteristics of interlayer in each block, the interlayer is divided into three types: stable, relatively stable and unstable. Based on the proportion of interlayer thickness greater than or equal to 2 meters, when the proportion is greater than 80%, it is considered that the interlayer distribution is stable, between 50% and 80%, and the distribution is relatively stable; when it is less than 50%, the distribution is unstable. According to the statistical results of the whole region, the interlayer distribution between sand groups and sublayers in each block is relatively stable, while the stability of PI 1 and PI 4 in sublayers is relatively poor. According to the distribution of barriers in each block, the barrier stability in block G6 is the worst, and the barrier stability in block A1 is the strongest.
Table 3. Statistical table of compartment distribution in Gulongnan area

| Interlamination | Interlayer thickness | Proportion of interlayer thickness | Distribution status |
|-----------------|----------------------|-----------------------------------|---------------------|
|                 | min | max | avg | <1  | 1-2 | 2-5 | >5 | >=2 |                      |
| PI1-1~PI1-2     | 0   | 5.9 | 2.1 | 33.0| 19.0| 45.5| 2.4| 48.0| Unstable              |
| PI1-2~PI12      | 0.7 | 8.6 | 4.4 | 2.4 | 15.2| 34.7| 47.7| 82.4| Stable                |
| PI2~PI13        | 1.1 | 11.5| 6.1 | 0.0 | 2.9 | 29.8| 67.3| 97.1| Stable                |
| PI3~PI4-1       | 1   | 10.4| 3.8 | 0.5 | 14.9| 68.2| 16.4| 84.6| Stable                |
| PI4-1~PI4-2     | 0   | 7.3 | 3.5 | 7.4 | 16.5| 54.9| 21.1| 76.0| More stable           |
| PI4-2~PI5       | 0.8 | 8.2 | 4.3 | 3.6 | 7.5 | 60.3| 28.6| 89.9| Stable                |
| PI5~PI6         | 1.1 | 11.5| 7.6 | 0.0 | 0.7 | 7.2 | 92.0| 99.3| Stable                |
| PI6~PI7         | 1.1 | 14.4| 9.4 | 0.0 | 0.7 | 1.9 | 97.3| 99.3| Stable                |
| PI7~PI8         | 4.7 | 18.4| 13.1| 0.0 | 0.0 | 0.2 | 99.8| 100.0| Stable               |

Table 4. G6 Statistical table of partition distribution in block

| Interlamination | Interlayer thickness | Proportion of interlayer thickness | Distribution status |
|-----------------|----------------------|-----------------------------------|---------------------|
|                 | min | max | avg | <1  | 1-2 | 2-5 | >5 | >=2 |                      |
| PI1-1~PI1-2     | 0.0 | 5.2 | 1.9 | 34.2| 20.8| 44.3| 0.7| 45.0| Unstable              |
| PI1-2~PI12      | 0.8 | 8.5 | 3.2 | 4.7 | 33.3| 36.7| 25.3| 62.0| More stable           |
| PI2~PI13        | 1.1 | 11.5| 5.5 | 0.0 | 2.7 | 41.3| 56.0| 97.3| Stable                |
| PI3~PI4-1       | 1.0 | 10.4| 3.1 | 0.7 | 22.0| 71.3| 6.0 | 77.3| More stable           |
| PI4-1~PI4-2     | 0.0 | 6.8 | 2.9 | 15.3| 14.7| 57.3| 12.7| 70.0| More stable           |
| PI4-2~PI5       | 0.8 | 8.1 | 3.6 | 6.1 | 18.9| 52.7| 22.3| 75.0| More stable           |
| PI5~PI6         | 2.6 | 11.5| 8.1 | 0.0 | 0.0 | 9.3 | 90.7| 100.0| Stable               |
| PI6~PI7         | 1.1 | 14.4| 9.6 | 0.0 | 1.3 | 3.4 | 95.3| 98.7| Stable                |
| PI7~PI8         | 5.1 | 17.9| 13.3| 0.0 | 0.0 | 0.0 | 100.0| 100.0| Stable               |

Table 5. Statistical table of interlayer distribution in M1 block

| Interlamination | Interlayer thickness | Proportion of interlayer thickness | Distribution status |
|-----------------|----------------------|-----------------------------------|---------------------|
|                 | min | max | avg | <1  | 1-2 | 2-5 | >5 | >=2 |                      |
| PI1-1~PI1-2     | 0.0 | 5.5 | 2.3 | 27.0| 17.5| 52.4| 3.2| 55.6| More stable           |
| PI1-2~PI12      | 0.8 | 8.1 | 5.9 | 0.8 | 0.0 | 15.2| 84.0| 99.2| Stable                |
| PI2~PI13        | 2.1 | 10.6| 6.8 | 0.0 | 0.0 | 11.9| 88.1| 100.0| Stable               |
| PI3~PI4-1       | 1.2 | 5.5 | 3.3 | 0.0 | 10.4| 88.8| 0.8 | 89.6| Stable                |
| PI4-1~PI4-2     | 0.6 | 6.7 | 3.6 | 4.8 | 18.3| 57.9| 19.0| 77.0| More stable           |
| PI4-2~PI5       | 1.0 | 8.2 | 4.7 | 0.8 | 0.8 | 64.0| 34.4| 98.4| Stable                |
| PI5~PI6         | 1.9 | 11.5| 7.7 | 0.0 | 0.8 | 7.2 | 92.0| 99.2| Stable                |
| PI6~PI7         | 5.0 | 12.7| 9.2 | 0.0 | 0.0 | 0.8 | 99.2| 100.0| Stable               |
| PI7~PI8         | 5.2 | 17.3| 12.8| 0.0 | 0.0 | 0.0 | 100.0| 100.0| Stable               |
Table 6. Statistical table of interlayer distribution in block D1

| Interlamination | Interlayer thickness | Proportion of interlayer thickness | Distribution status |
|-----------------|----------------------|-----------------------------------|---------------------|
|                 | min | max | avg | <1  | 1-2 | 2-5 | >5  | >=2 |
| PI1-1~PI1-2     | 0.0 | 5.9 | 1.6 | 43.9| 24.4| 26.8| 4.9 | 31.7|
| PI1-2~PI2       | 0.7 | 7.3 | 4.7 | 4.9 | 12.2| 22.0| 61.0| 82.9|
| PI2~PI3         | 1.2 | 9.9 | 7.3 | 0.0 | 9.8 | 12.2| 78.0| 90.2|
| PI3~PI4-1       | 1.0 | 9.4 | 4.0 | 2.4 | 21.4| 73.8| 2.4 | 76.2|
| PI4-1~PI4-2     | 1.3 | 7.3 | 4.0 | 0.0 | 19.5| 41.5| 39.0| 80.5|
| PI4-2~PI5       | 0.8 | 8.1 | 3.7 | 12.2| 4.9 | 68.3| 14.6| 82.9|
| PI5~PI6         | 2.0 | 10.8| 6.1 | 0.0 | 4.9 | 9.8 | 85.4| 95.1|
| PI6~PI7         | 2.0 | 14.2| 10.3| 0.0 | 2.4 | 0.0 | 97.6| 97.6|
| PI7~PI8         | 6.1 | 18.4| 13.8| 0.0 | 0.0 | 0.0 | 100.0| 100.0|

Table 7. Statistical table of interlayer distribution in block A1

| Interlamination | Interlayer thickness | Proportion of interlayer thickness | Distribution status |
|-----------------|----------------------|-----------------------------------|---------------------|
|                 | min | max | avg | <1  | 1-2 | 2-5 | >5  | >=2 |
| PI1-1~PI1-2     | 0.0 | 5.4 | 2.2 | 34.3| 16.2| 46.5| 3.0 | 49.5|
| PI1-2~PI2       | 1.5 | 8.6 | 4.3 | 0.0 | 8.1 | 61.6| 30.3| 91.9|
| PI2~PI3         | 1.1 | 11.3| 5.5 | 0.0 | 4.0 | 42.4| 53.5| 96.0|
| PI3~PI4-1       | 1.5 | 9.3 | 5.2 | 0.0 | 7.1 | 45.5| 47.5| 92.9|
| PI4-1~PI4-2     | 0.0 | 7.2 | 4.0 | 2.0 | 16.0| 53.0| 29.0| 82.0|
| PI4-2~PI5       | 3.2 | 7.8 | 4.9 | 0.0 | 0.0 | 63.6| 36.4| 100.0|
| PI5~PI6         | 3.4 | 10.9| 7.6 | 0.0 | 0.0| 3.1 | 96.9| 100.0|
| PI6~PI7         | 3.2 | 13.2| 9.0 | 0.0 | 0.0| 2.0 | 98.0| 100.0|
| PI7~PI8         | 4.7 | 17.5| 12.7| 0.0 | 0.0| 1.0 | 99.0| 100.0|

2.4. Plane heterogeneity
Plane heterogeneity refers to the heterogeneity caused by the plane changes of geometry, scale, continuity, porosity and permeability of sand body, which has great influence on well pattern arrangement, plane sweep efficiency of injected water and plane distribution of remaining oil [2, 15-18]. According to the logging interpretation results, the sand penetration rate, sand thickness and reservoir physical properties of each sedimentary unit in each block are counted (Figure 6~ Figure 8). According to statistics, the drilling rate of sand bodies and physical properties of reservoirs in different sub-layers of different blocks are quite different. The drilling rate of sand bodies in block G6 is the highest, while the drilling rate of sand bodies in block A1 is the lowest. It can be seen from the permeability plane distribution map of each block that the high permeability area mainly develops in the center of river channel.
Figure 6. Histogram of drilling rate of sandstone in each sublayer

Figure 7. Histogram of average drilled sandstone thickness

Figure 8. Isogram of facies-controlled permeability of sedimentary units in Gulongnan area
3. Application Effect
By studying the heterogeneity in Gulongnan area, the development and adjustment of the block are guided.

First, guide the injection allocation scheme of new investment blocks and determine water injection parameters. The combination relationship of injection-production wells is divided into three categories, and the water injection policy of each contact relationship is determined. The injection allocation scheme is prepared according to the optimal injection-production ratio, which guides the injection allocation scheme of 29 horizontal wells.

The second is to provide the basis for water breakthrough analysis of horizontal wells, and guide the tracking adjustment of water injection scheme. According to the plane contact relationship of sand body, adjust the water injection intensity of each section of horizontal well in time, promote the effective delay of water breakthrough, and promote the water cut recovery by strengthening or weakening the water injection in the main layer. The effective time is advanced 28 days in advance; The water exposure time was extended by 65 days. 20 wells were reduced from high water cut to medium and low water cut.

4. Summary
The overall reservoir heterogeneity of the Gulongnan area is strong. From the perspective of sedimentary units, the heterogeneity of PI1, PI3 and PI6 is strong, while the heterogeneity of PI2 and PI7 is weak, and the other units are between between the two. Seen from each block, the heterogeneity in well G6 is weak, the heterogeneity in well M1 and A1 is strong, and the heterogeneity in block D1 is the strongest. Along the north-south provenance direction, the heterogeneity in the well areas G6, M1 to A1 gradually increases, and the heterogeneity in the well area D1 is the strongest due to the influence of two provenances. The study of heterogeneity in Gulongnan area effectively guides the optimization of injection allocation scheme for new wells in this area, promotes the effectiveness of oil wells, delays water breakthrough time, and provides strong support for water breakthrough analysis of horizontal wells.

References
[1] Xia Nan, Yan Xiaolin, Liu Jinlian. The influence of reservoir heterogeneity in Baoyue block on water injection development. Petrochemical Technology, Vol. 23 (2016) No. 2, p. 188
[2] Du Wei. A review of research methods on reservoir heterogeneity. Groundwater, Vol. 38 (2016) No. 1, p. 242-243
[3] Bu Fanqing. Research on reservoir heterogeneity and its application in fan delta oilfield. Petrochemical Technology, Vol. 24 (2017) No. 3, p. 118-119
[4] Baiyang. Current status and prospects of research on reservoir heterogeneity. Petrochemical Technology. Vol. 26 (2019) No. 1, p. 238
[5] Lu Wei, Ma Tao, Qu Ceji. Study on the heterogeneity of reservoirs in Changguanniaob oil area of Yanchang Oilfield. China Petroleum and Chemical Standards and Quality, Vol. 33 (2012) No. 12, p. 141
[6] Li Ting, Zhao Junlong, Xu Jiantao, etc. A review of research methods and techniques of reservoir heterogeneity. Shaanxi Coal, Vol. 32 (2013) No. 1, p. 62-64.
[7] Hu Ji. Research on quantitative evaluation of interlayer heterogeneity in oilfield. Knowledge Economy, (2011) No. 13, p. 70
[8] Sun Bo, Zhou Xiaoxing. Quantitative study on the heterogeneity of Chang 8 reservoir in Area B of Ordos Basin. Petrochemical Industry Application, Vol. 35 (2016) No. 2, p. 78-81.
[9] Zhang Chenxu. Discussion on research methods and technology advancement of reservoir heterogeneity. Petrochemical Technology, Vol. 24 (2017) No. 11, p. 163
[10] Hong Feng, Jiang Lin, Hao Jiaqing, et al. Origin of heterogeneity of oil and gas reservoirs and analysis of oil and gas content. Natural Gas Geoscience, Vol. 26 (2015) No. 4, p. 608-615
[11] Pan Ling, Fang Quantang, Duan Yonggang. Research on the influence factors of low permeability reservoir heterogeneity on recovery factor. Journal of Southwest Petroleum University
(Natural Science Edition), Vol. 34 (2012) No. 3, p. 111-115

[12] Xiao Juan. Study on the heterogeneity of reservoirs in the Pu 47 block of Yongle oil field. Journal of Yangtze University (Self Science Edition) Science and Technology Volume, Vol. 07 (2010) No. 3, p. 206-208

[13] Shang Yuenan, Yuan Shuai. Research on macro-heterogeneity of low permeability sandstone reservoirs. Petrochemical Technology, (2015) No. 12, p. 204-204,201

[14] Zhao Hesen, Tang Bo, etc. Research on the heterogeneity of Chang 2 reservoir in Dingbian area, Ordos Basin. Lithologic reservoirs, Vol. 23 (2011) No. 4, p. 70-74

[15] Tang Ding, Zhang Chunsheng, Xiao Menghua. Study on the macroscopic heterogeneity of Chang 61 reservoir in Panguliang area, Ordos Basin. Petroleum Geology and Engineering, Vol. 25 (2011) No. 1, p. 32-34,38

[16] Zhang Manting, He Wenxiang, Wang Kai. Research on Heterogeneity of Reservoir in Hai 26 Fault Block. Journal of Yangtze University (Self Science Edition) Petroleum/Agriculture Mid-term Journal, Vol. 12 (2015) No. 5, p. 10-14

[17] Han Yu. The influence of reservoir heterogeneity on oilfield development. Chemical Engineering and Equipment, (2017) No. 1, p. 131-133

[18] Yan Haijian, Yang Qiqi, Hu Hehe, etc. Research on the heterogeneity of Chang 2 reservoir in Wayaopu block. Liaoning Chemical Industry, Vol. 44 (2015) No. 11, p. 1375-1377