Heterogeneity evaluation method for double-high stage of fault block reservoir and its application

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Abstract. The study of reservoirs’ macro-heterogeneity is one of the important research contents of secondary development and tertiary oil recovery in high water cut period reservoirs. The GX oilfield is a terrestrial sedimentary fault block reservoir. In the development area, there main develop structure reservoir, and the faults are developed intricately. Due to the combined effects of sedimentary environment, diagenesis and tectonism, the heterogeneity of reservoir plane and longitudinal are extremely strong, and the geological characteristics and development effects of different development units in the same interval are great different. In this paper, the GX1 fault block is taken as an example. The thickness of the reservoir, the geometry of the oil layer and the uneven distribution of the permeability are considered on the plane. The overlap of the sand body, the interlayer and the intra-layer permeability difference are considered on the longitudinal direction. Through the conduct research on the well pairs that have established the corresponding relationship between injection and production, regarding the quantitative results of the seepage capability between wells as basis, also considering the characteristics of stage development, to carry out the time-varying of heterogeneous and the target block’s seepage capacity from the dynamic point of view. The research provides scientific support for the secondary development adjustment, tertiary oil recovery design and “two-three combination” enhanced oil recovery technology research to GX oilfield.

1. Introduction

Reservoir heterogeneity refers to the uneven variation in spatial distribution and its properties, is affected by sedimentary environment, diagenesis and tectonism during the formation of reservoirs, including pore heterogeneity, plane heterogeneity and Longitudinal heterogeneity [1-4]. Plane heterogeneity refers to the geometry, scale, continuity of a reservoir sandstone body, and the heterogeneity caused by the...
spatial variation of porosity, permeability and thickness in the sand; longitudinal heterogeneity including intra-layer heterogeneity and interlayer heterogeneity.

At present, the oilfields in the eastern terrestrial sedimentary area have successively entered the stage of double-high mining stage——high-water-cut and high-recovery, facing the problem of increasingly serious development contradictions [8-12]. At this stage, there is still a large amount of remaining oil in the main and secondary main layers, and exhibits the characteristics of overall high dispersion and local relative enrichment. The comprehensive study of reservoir heterogeneity runs through various oilfield development stages such as early reservoir geological analysis, development process effect evaluation, post-development program adjustment and tertiary oil recovery design [14, 15]. Reservoir heterogeneity is not only an important factor in controlling oil and gas reservoirs, but also a major factor affecting fluid movement and residual oil distribution control during oilfield development process. It is the material basis for residual oil distribution research, only on the basis of fine characterization of reservoir heterogeneity, can propose targeted enhanced oil recovery techniques [16].

2. Establishment of heterogeneous evaluation method

2.1 Comprehensive evaluation method of seepage capability

There is a injection-production wells pair, the connected permeability between the injection-production wells and the nearby formation is a certain value, and the injection and output of the injection-production wells are not affected by other wells, and the wellbore radius of injection well and production well is equal.

![Interwell schematic diagram](image)

**Figure 1.** Interwell schematic diagram

Calculation formula for connection permeability between the injection-production wells:

\[
k = \left( \frac{Q_1 + Q_2}{2\pi h\Delta P} \right) \mu \ln \frac{L}{r_w} \times \frac{10^{15}}{86400 \times 10^3 \times 10^6} = \left( \frac{Q_1 + Q_2}{2\pi h\Delta P} \right) \mu \ln \frac{L}{r_w} \times \frac{10^6}{86400}
\]  

(1)

Where \(Q_1\) is Daily water injection, \(Q_2\) is Daily fluid production, \(\mu\) is Apparent viscosity, \(m^3/d; \mu\) is Apparent viscosity, \(mPa\cdot s\), calculated with permeability saturation curve; \(h\) is Reservoir thickness, \(m\), average value of connected interval of the injection-production wells; \(\Delta P\) is Well bottom pressure difference of the injection-production wells, \(MPa\); \(L\) is well spacing, \(m\); \(r_w\) is Well radius, \(m\); \(k\) is Inter-well connected permeability, \(mD\).
2.2 Reservoir heterogeneity evaluation method

Permeability variation coefficient is an important parameter for characterizing reservoir permeability heterogeneity and an important factor affecting oilfield recovery. It has a wide range of applications in reservoir engineering and geological research. When a injection well corresponds to multiple production wells or a production well has multiple injection wells corresponding to it. The plane permeability variation coefficient of a well is calculated by the connected permeability at same well.

\[
V_K = \frac{\sigma_k}{k} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} \left( k_i - \bar{k} \right)^2}
\]

Where \( \sigma_k \) is Standard deviation of sample permeability, mD; \( \bar{k} \) is Sample permeability mean, mD; \( \bar{k} = \frac{\left( \sum_{i=1}^{n} k_i \cdot h_i \right)}{\sum_{i=1}^{n} h_i} \); n is Sample quantity; \( k_i \) is Permeability of sample i, mD; \( h_i \) is Effective thickness, m; \( h_i \) is Effective thickness of sample i, m.

3. Application example

3.1 Geological characteristics of target reservoir

The GX1 fault block in the GX oilfield belongs to continental facies deposition, which is influenced by the comprehensive control of several main faults and secondary faults. The buried depth of the reservoir is 618.4m to 1395m. The plane continuity of reservoir is poor and the reservoir thickness is medium. There are many oil bearing series in the longitudinal direction, and the interlayer distribution is uneven. Reservoir physical properties are mainly high porosity and permeability, with an average porosity of 31% and an average permeability of 524×10^{-3} μm², and no uniform oil-water interface. Most of the development areas are commingled injection and extraction wells. Due to the severe heterogeneity of the reservoir plane and longitudinal, the injected water advances along each layer at different speeds, which seriously restricts the development effect of the reservoir. After more than 50 years of development and adjustment and frequent reperforation and altering layers, it is difficult to evaluate dynamic heterogeneity.

3.2 Comprehensive evaluation of heterogeneity

(1) Data processing
   a. Injection/production well data processing and bottom hole flowing pressure variation law analysis, interwell injection-production correspondence analysis and statistics;
   b. Production stage division according to stage development goals and stage development characteristics;

| Unit     | Stage division                                      | Start date | End date | Number of injector producer pair |
|----------|-----------------------------------------------------|------------|----------|---------------------------------|
| GX1-1    | Well pattern improvement and production increasing stage | 1966       | 1976     | 12                              |
|          | Production decline stage                            | 1977       | 1991     | 35                              |
|          | Well pattern thickening stage                       | 1992       | 1996     | 76                              |
|          | Well extension, reserve increasing and comprehensive adjustment stage | 1997       | 2005     | 197                             |
|          | 2006 to present                                    | 2006       | present  | 537                             |

Table 1. Production stage division
c. basic data such as stage division date of each development units, bottom hole flowing pressure of injection and production well, effective thickness of interwell, and performance data of injection and production well over the years are input in reservoir heterogeneity comprehensive evaluation model. Finally the comprehensive evaluation of interwell seepage capacity and heterogeneous time-variant property is completed.

(2) Results and cognition of heterogeneous comprehensive evaluation

![Figure 2](image1.png)

**Figure 2.** Coefficient of permeability variation at different development stage

![Figure 3](image2.png)

**Figure 3.** Coefficient of permeability variation distribution frequency of development unit GX1- I
4. Conclusion
(1) From the perspective of dynamic change, interwell seepage capacity time-variant evaluation model and heterogeneous time-variant evaluation model are established based on Quantitative result of interwell seepage capacity and development characteristics of different stage. These two models consider thickness of reservoir, geometry of oil layer and uneven distribution of permeability in the plane. In addition, these two models consider characteristics of sand body superimposition, interlayer and intralayer permeability difference in the vertical.
(2) Coefficient of permeability variation of development unit GX1-I was 0.47 at initial stage of production. With the continuous adjustment of development, the degree of reservoir heterogeneity has been significantly increased, and has now risen to 1.05.

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