Calculation Method for Preferential Flowing Channel in Pinghu Oil Field

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Abstract: ***During the development of oil reservoir with bottom water, the pore structure could be changed under the long time washing by oil and water, and the Preferential Flowing Channel will be created. As a result, the bottom water will preferentially flow through these channels, and furthermore enhance the water cut and reduce the oil recovery. In order to reduce water cut and finally enhance oil recovery, the adjustment cases for the oil field should be designed under the research of multi-phase flow. This paper presents the Calculation Method for Preferential Flowing Channel and the calculation results of the layers in Pinghu oil field. The result could provide theoretical basis for next study of Adjustment Cases***

Keywords: Preferential Flowing Channel, Water Cut, EOR

1. Introduction

High water cut is a serious problem for bottom oil field during the later period of development. Pinghu Oil Field, which located in East China Offshore, has increasing water cut and even worse condition in recent years. The pore structure has been changed under the long time washing by oil and water, therefore, the Preferential Flowing Channel will be created. As a result, the bottom water will preferentially flow through these channels, and furthermore enhance the water cut and reduce the oil recovery. This study presents the Calculation Method for Preferential Flowing Channel, the result could provide theoretical basis for next study of Adjustment Cases.

2. Mathematics

2.1 Distribution of the high capacity channel

Assuming: developing time is t, recovery is B%, water cut in time t is A%, water break point is O, and production well locates in point W. As can be seen in Figure 1, the pressure gradient will reach the largest value near the line segment OW.

The parameter α could be calculated by the formula as follow:

$$1-2\int_0^1 x^\alpha dx = B\% \qquad (1)$$

The axis of symmetry between high boundary and low boundary in the high capacity channel could be expressed as follow:

$$y = x^\alpha, \quad x \in [0,1] \qquad (2)$$

The distribution of the high capacity channel could be calculated by this method. As shown in Figure 1, the oil which located in shadow area had been produced, and the percentage of the total acreage is B%. As a result, the percentage (1-B%) are the remain oil.

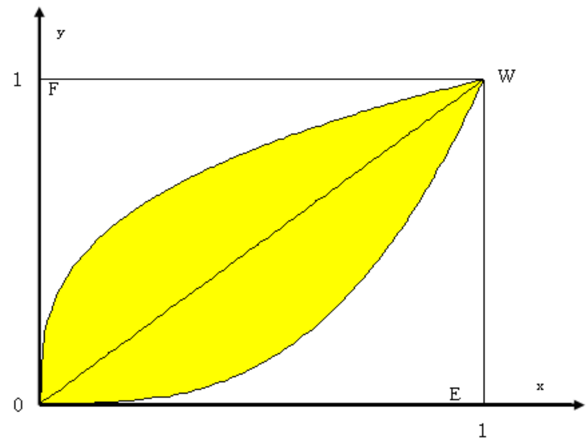

Figure 1: Distribution of the high capacity channel

While the different value of α means different low boundary, and also will change the distribution of the high capacity channel. Assuming: in the S1 area (Figure 2), the recovery is B%, the value α will fit the formula as follow:

$$\frac{\frac{1}{2}-\int_0^1 x^{\alpha_1} dx}{\frac{1}{2}-\int_0^1 x^{\alpha} dx} = \frac{S_1}{S} \qquad (3)$$

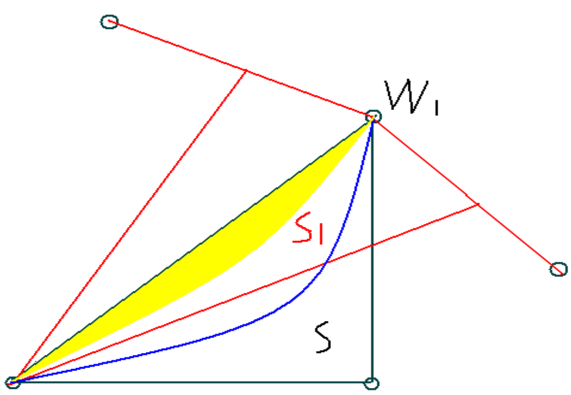

Figure 2: Distribution of the high capacity channel under the change of α

2.2 Distribution of Core Radius

Assuming: the formation has n anisotropic layers in the vertical direction, in a research time during the later period of the development, the recovery in each layer could be calculated and was named Bi%, i=1, 2, …, n. The water-oil ratio in layer i could be calculated as follow:

$$C_i = \frac{q_{iw}}{q_{io}} = \frac{A_i}{1-A_i} \quad (4)$$

Where Ai is the water cut in layer i, the formula could be expressed as follow:

$$C_i = \frac{\frac{K_{iw}}{\mu_w} B_i\%}{\frac{K_{io}}{\mu_o}(1-B_i\%)} \quad (5)$$

Where K_{io}, μ_o, μ_w, Bi% are known quantity, and the water permeability in layer i could be calculated as follow:

$$K_{iw} = \frac{\frac{\mu_w}{\mu_o} C_i K_{io}(1-B_i\%)}{B_i\%} \quad (6)$$

The average radius of the pores which were fulfilled by water could be calculated as follow:

$$\overline{r}_{iw} = \sqrt{\frac{8K_{iw}}{\phi_{iw}}} \quad (7)$$

Where φ_{iw} is the porosity in water flow section, the unit of K is Darcy, and r is CM, the eq (7) could be expressed as follow:

$$\overline{r}_{iw} = \frac{2}{7\times10^3}\sqrt{\frac{K_{iw}}{\phi_{iw}}} \quad (8)$$

The average radius of the pores which haven't been fulfilled by water could be calculated as follow:

$$\overline{r}_{io} = \sqrt{\frac{8K_{io}}{\phi_{io}}} = \frac{2}{7\times10^3}\sqrt{\frac{K_{io}}{\phi_{io}}} \quad (9)$$

Define λ_i as follow:

$$\lambda_i = \frac{\overline{r}_{iw}}{\overline{r}_{io}} \quad (10)$$

And the radius calculated by eq(9) and eq(10) obeyed the lognormal distribution, and could be expressed as follow:

$$r_{io} \sim N(\overline{r}_{io}, \sigma_{io}^2)$$
$$r_{iw} \sim N(\overline{r}_{iw}, \sigma_{iw}^2) \quad (11)$$

Define σ_{io} as the RMS error, it could be measured by experiments in lab or calculated as follow:

$$\sigma_{io} = \frac{r_{io\max} - r_{io\min}}{6} \quad (12)$$

2.3 Calculation method for areal heterogeneity

Divide the area [0, Re] into 100 equal parts, as shown in Figure 3. The cell is Re/100.

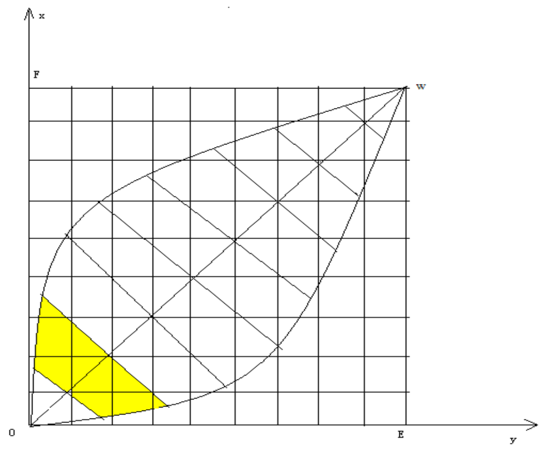

Figure 3: Area cells

In each cell, the flow is single phase and one direction, based on Darcy law, the flow rate in No. j cell could be calculated as follow:

$$Q_j = \frac{K_j A_j \Delta P_j}{a\mu L} \quad (13)$$

Where A_j is the water flow area in No. j cell, m2; K_j is permeability, mD; ΔP_j is the pressure difference, MPa; Q_j is the production, m^3/d; L is the length Re/100, m; μ is the viscosity, mPa•s; a is coefficient for correction.

The Kj could be calculated as follow:

$$K_j = \frac{aQ_j \mu L}{A_j \Delta P_j} \quad (14)$$

3. Results

In this study, the pore radius ranges were divided into 4 levels:

- Large: Rw≥7μm;
- Medium: Rw∈[5μm ,7μm];
- Small: Rw∈[3μm , 5μm];
- Tiny: Rw≤3μm.

For the typical 4 layers, the calculation results are listed in Table 1.

The ratios of each level of pores in the typical 4 layers are listed in Figure 4.

Table 1: Calculation results of the typical 4 layers

Layer	Pore Volume, Total, m3	Pore Volume, Large, m3	Pore Volume, Medium, m3	Pore Volume, Small, m3	Pore Volume, Tiny, m3
1	28352.78	422.3464	1138.616	7019.176	19772.64
2	10767.33	379.246	918.6909	4530.12	4939.277
3	34128.88	349.6601	965.0779	6577.277	26236.87
4	40142.44	975.3623	3506.843	19442.55	16217.69

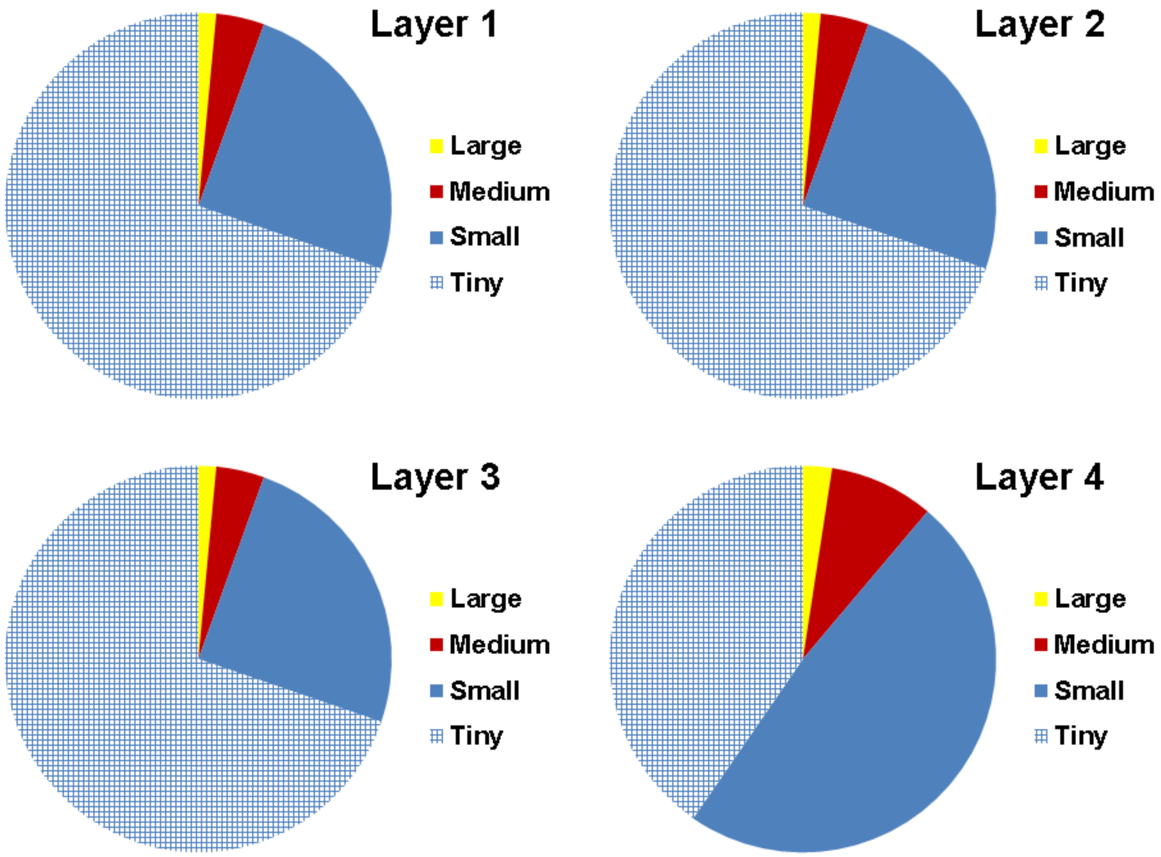

Figure 4: Ratios of each level of pores in 4 layers

4. Conclusions

The following conclusions could be drawn according to the results obtained in this study:

- The distribution of the radius of pores could be calculated by theoretical methods presented in this paper.
- The areal heterogeneity could be calculated based on the distribution of pores' radius.
- The distribution of the Preferential Flowing Channel could be calculated and made drawing by the distribution of pore radius and permeability.
- The result could provide theoretical basis for next study for Adjustment Cases

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Author Profile

Yangfan Li received the Master degree in Yangtze University (China). He is currently a petroleum engineer in CNOOC (China National Offshore Oil Company). His research interests include energy, petroleum, fluid mechanics, etc.