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Investigation of parameter limit of selecting polymer flooding potential block at the Pubei Oilfield

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Abstract. The Pubei oilfield belongs to the reservoir with low permeability and poor physical property. It has entered the late period of high water cut stage, so it needs polymer flooding to produce remaining oil. In order to pursue benefits and avoid risk, it is necessary to select potential block of polymer flooding by optimum parameters. In the paper, the limit of permeability for selecting potential block of polymer flooding is calculated by using both reservoir engineering method and economic analysis theory.

1. Introduction
The Pubei oilfield, a low permeability reservoir, has entered the late period of high water cut stage, with the production declining significantly[1-2]. The polymer flooding pilot test carried out from 2000 to 2006 achieved better results that cumulative oil increment is $6.17 \times 10^4$ t and enhanced oil recovery is 5.84%. The polymer flooding field test with dense well pattern has been carried out since 2014, which enhanced oil recovery is forecasted 7.65 %. Various types of field test showed that polymer flooding can further enrich the means of producing remaining oil potential and have the feasibility of practice in the narrow and thin sandstone oilfield [3-4].

Because it need capital investment more than water flooding, it is necessary to select potential block of polymer flooding by optimum parameters [5]. The permeability is a vital parameter that can assess whether polymer flooding is technically feasible. So it is crucial to calculate the limits of permeability for selecting potential block of polymer flooding. The author calculates the limits by using both reservoir engineering method and economic analysis theory, and confirms the rationality by taking advantage of the existing experimental results and the analysis of injection profile resulting from measured datum of polymer flooding well.

2. Limits of economic output of single well
According to the principle of profit and loss balance, the limits of economic output of single well is the output when the total costs of the oil well and the total incomes are equal [6]. The basic formula is:

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Where:

- $Q_{\text{min}}$ — Limits of economic annual output of single well, t;
- $R$ — Commodity rate of crude oil, %;
- $P_o$ — Price of crude oil, Yuan/t;
- $V$ — Operation cost of crude oil, Yuan/t;
- $F$ — Fixed annual costs, including the cost of new well, pharmacy and ground construction costs, yuan.

So the limits of economic output of single well can be calculated as follows:

$$Q_{\text{min}} = \frac{F}{(P_o \cdot R - V)}$$

Among them, the definition of the commodity rate of crude oil refers to the proportion of the commodity volume of crude oil production accounted for the total output of crude oil. The commodity of crude oil is equal to the total output of crude oil minus the amount of own oil consumption and the evaporation loss during production. But the commodity rate of crude oil in this paper is 100%. Fixed cost and operating cost of crude oil are used to learn from the cost of polymer flooding test block of Pubei oilfield, crude oil prices in accordance with $70$ barrel to calculate (although the price is lower than $70$ at present, this study can be seen as a technology applied in the future). At last the limits of economic annual output of single well of polymer flooding is calculated by using the second formula, and the value is 993t.

### 3. Technical and economic limits of polymer flooding reservoir

The research that theoretical formula deduction and calculation of permeability limit for polymer flooding reservoir needs to use the limits of economic annual output of single well model and the basic theory of the fluid mechanics in porous medium.

The rheological properties of the polymer flooding reservoir are basically in accordance with the power law model, and the inflow performance relationship of the polymer flooding oil well can be obtained according to the flow law of the power law fluid. Due to the influence of shear degradation, the rheological parameters (consistency coefficient and flow index) of the formation fluid are changing continuously along the flow direction, which makes it difficult to solve and the accuracy is poor. Therefore, some scholars give a semi-empirical equation on the basis of theoretical analysis [7].

$$p_e - p_{\text{of}} = Aq^{nh}$$

Thereof:

$$A = a \left[ \frac{\mu_s (r_e^{1-n} - r_w^{1-n})}{2\pi h^2 (1-n)K} \right]$$

Where:

- $q$ — Daily output of single well, m$^3$/d;
- $p_e$ — Supply edge pressure, MPa;
- $p_{\text{of}}$ — Bottom flowing pressure, MPa;
- $\mu_s$ — Effective viscosity of polymer solution, Pa.s;
- $n$ — Polymer solution flow index, 0 < n < 1;
- $K$ — Permeability of formation, $\mu$m$^2$;
- $h$ — Effective thickness, m;
- $r_e$ — Drainage radius, m;
- $r_w$ — Bottom hole radius, m;
According to the datum of ten wells listed in Table 1, making regression according to the third formula, the values of $a$ is 24.66 and the values of $b$ is 0.3.

Assuming $U = h^e \cdot K$, then $a$, $b$, $Q_{\min}$ and other parameters in the Table 2 are substituted into the third formula, and the minimum value of $U$ can be calculated. When effective thickness is taken as the average (in the paper, the average effective thickness is 9m in the Pubei oilfield), the minimum value of the permeability $K$ can be calculated as $170 \times 10^{-3} \mu m^2$.

Based on the above calculation, we determine that the limit of the permeability for polymer flooding in Pubei oilfield is $170 \times 10^{-3} \mu m^2$.

### 4. Proof the permeability limits of polymer flooding reservoir is reasonable

#### 4.1. Existing experiment on the adaptability of polymer molecular weight to core permeability

The injection capacity of the two kinds of polymers are determined under the condition of 800mg/L of salt resistant polymer concentration, 1000mg/L of the common polymer concentration[8-9]. Research results (Figure 1) show that when the air permeability of reservoir is greater than $150 \times 10^{-3} \mu m^2$, there is no blocking when injecting salt resisting polymer (8 million molecular weight) or common polymer (12 million molecular weight). Therefore, the reservoir whose air permeability is greater than $150 \times 10^{-3} \mu m^2$ is adaptive with the low and middle salt resisting polymer and the common middle polymer. So the limit of the permeability for polymer flooding is consistent with the experimental results.
According to the pilot test of 8 wells from continuous injection profile data of polymer flooding (molecular weight of salt resisting polymer is 8 million) in Pubei Oilfield, the result shows that from the beginning of blank water flooding to 2006, the decline range of relative fluid amount of accepting fluid zones, which permeability is less than 100×10^-3 μm², is large after injection of polymer solution. But the amount in accepting fluid zones whose permeability is more than 150×10^-3 μm² increases during polymer flooding, increased from 76.41% during water flooding to 90.98% in 2006. It demonstrates that the main accepting fluid zones are channel sand whose permeability is more than 150×10^-3 μm². So the limit of the permeability for polymer flooding is consistent with the analysis result of injection profile.

Table 3. The entry profile statistics of Pubei oilfield

| Permeability range (10^2 μm²) | Thickness (m) | Absorbed thickness ratio (%) | Water thickness ratio (%) | The relative amount of accepting liquid (%) |
|-------------------------------|---------------|-----------------------------|--------------------------|-------------------------------------------|
| 0-50                          | 12            | 7.6                         | 0.7                      | 0.46 0.4 0.5 0.2 0.4 0.4                  |
| 50-100                        | 19            | 13.1                        | 7.9                      | 31.6 9.46 2.1 3.1 3.8 3.9 3.1            |
| 100-150                       | 21            | 16.6                        | 7.7                      | 42.9 8.84 5.6 6.4 4.2 5.2 5.6            |
| 150-200                       | 7             | 5.3                         | 4.2                      | 39.2 2.10 4.8 5.6 3.4 4.1 4.27           |
| 200-250                       | 6             | 9.2                         | 7.8                      | 84.6 5.44 7.6 6.7 7.0 8.1 10.3 9.82      |
| 250-300                       | 11            | 20.7                        | 17                       | 15.7 84.7 6.59 11.3 11.3 10.2 14.9 14.3 14.14 |
| 300-350                       | 18            | 43.4                        | 37.6                     | 34.8 100 39.54 36.8 30.0 26.2 28.3 29.0 31.31 |
| 350-400                       | 3             | 10.6                        | 10.2                     | 9.4 100 12.23 11.6 12.3 13.8 12.0 12.7 11.62 |
| 400-500                       | 1             | 5.8                         | 5.5                      | 5.1 100 4.49 5.0 11.2 12.0 13.0 12.0 9.81 |
| More than 500                 | 2             | 10.4                        | 9.6                      | 8.9 100 6.02 17.1 15.7 15.2 12.3 8.2 10.01 |

Figure 1. The adaptability of polymer molecular weight to core permeability.

4.2. Comparative analysis of injection profile of polymer flooding well

The entry profile statistics of Pubei oilfield.
5. Conclusions

- According to the principle of profit and loss balance, the limit of economic annual output of single well by polymer flooding is 993t by calculation.
- Using the limits of economic annual output of single well model and the basic theory of the fluid mechanics in porous medium, the limit of the permeability is $170 \times 10^{-3} \mu m^2$ for polymer flooding in Pubei oilfield.
- This method has been confirmed by existing experimentation and analysis of injection profile resulting from measured datum of polymer flooding well, so it can be applied to select potential block of polymer flooding at Pubei oilfield. The method maybe applied to other oilfields, but it needs confirmation prior to the application.

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