Difference Analysis of Polymer Injection under Constant Velocity and Pressure Conditions

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Abstract. In the later stage of polymer flooding, in order to achieve high polymer recovery, high polymer flooding is started. Before injection, it is necessary to clarify the difference of polymer model with constant velocity or constant pressure, and provide technical support for the smooth polymer injection. Under the condition of constant velocity and constant pressure, the injection process of polymer solution was simulated and compared with the criterion of injection capacity in two cases. Furthermore, the applicable scope of polymer injection with constant velocity and constant pressure was further clarified. The test shows that, (1) at constant speed under the condition of 0.2ml/min, 16 million and 25 million molecular polymers can't be injected into layer of 200×10⁻³µm² permeability. (2) In cores of 200×10⁻³µm² permeability, polymer is injected at 0.1 and 0.15 MPa/m under the condition of constant pressure, according to the experimental results, the recommended flooding concentration is 1000 ~ 1500mg/L (16 million molecular), 1000mg/L (25 million molecular). (3) In cores of 300×10⁻³µm² permeability, in addition to the 2000mg/L velocity injection of 25 million polymers, the injection of other molecules with constant velocity or constant pressure is successful, and all of them are available. (4) In short, in cores of 200×10⁻³µm² permeability, constant pressure injection can be injected smoothly under the condition of low polymer concentration, compared to constant speed under the condition of difficult injection / jam, constant velocity injection has more advantages to select more improve polymer injection methods. This study can provide technical support for polymer flooding mode selection in the late stage of polymer flooding.

Key words: polymer, constant speed, constant pressure, Injection capacity.

1. Overview of test area
Pu I3 is the target layer of polymer flooding in Xing Nan development zone. It belongs to distributary plain facies and inner leading-edge facies deposition. The reservoir rocks are mainly fine sandstones, with a particle range of 0.05-0.42mm, a median particle size of 0.120mm and an average porosity of 29.41%. Ground degassed oil density is 0.8510g/cm³, crude oil viscosity is 13.9MPa·s on the ground, underground oil viscosity 6.7MPa·s, wax content 21.5% and 10.7% rubber content, the volume coefficient of 1.115, the saturation pressure of 7.08MPa, the original gas-oil ratio 42.9m³/t. The relative density of natural gas is 0.6181, the content of methane is 87.63%, and the content of carbon dioxide is 0.77%. Oilfield water belongs to NaHCO₃ type of land phase generated water, which is characterized by
high content of chlorine, sodium, potassium, bicarbonate ions, stable content of calcium and magnesium ions, low content of rare elements and naphthenic acid.

2. Experiment part

2.1. Constant speed test
Under the condition of constant velocity, polymer solutions with different molecular weights [8-9] and concentrations are injected into cores of different permeability, and the injection situation of polymer solutions is characterized by evaluating pressure changes.

2.1.1. Experimental conditions:
(1) Experimental water: water experiments for Daqing oil production plant Pu I reservoir deep sewage (between sewage and clear water composition are shown in table 1), before use, filtered by 0.2µm microporous filter, remove the impurities.
(2) Experimental core: choose Φ25x100mm columnar artificial core to carry out injection capacity assessment.
(3) Experimental solution: the experimental solution is a solution of 1000 mg/L, 1500 mg/L and 2000mg/L of dry polymer powder with a molecular weight of 16 million and 25 million respectively. (see table 2 for the relationship between polymer concentration and viscosity).
(4) The experimental temperature: 45°C.

| Water samples                  | CO₃²⁻ mg/L | HCO₃⁻ mg/L | Cl⁻ mg/L | SO₄²⁻ mg/L | Total anion mg/L | Ca²⁺ mg/L | Mg²⁺ mg/L | K⁺+Na⁺ mg/L | Total salinity mg/L |
|-------------------------------|------------|------------|----------|------------|-----------------|-----------|-----------|-------------|---------------------|
| pure water                    |            | 602.27     | 88.63    | 48.03      | 12.40           | 60.12     | 15.19     | 198.95      | 984.50              |
| Deep treated sewage           | 112.82     | 2122.28    | 1116.68  | 12.01      | 68.29           | 15.03     | 6.08      | 1587.92     | 4972.80             |

Table 2. Concentration and viscosity of polymer solution

| concentration (mg/l) | viscosity(MPa·s) |
|---------------------|-----------------|
|                     | 16 million molecular polymers | 25 million molecular polymers |
| 1000                | 25.3            | 37.3            |
| 1500                | 50              | 71.4            |
| 2000                | 94.3            | 150.5           |

2.1.2. Experimental scheme. (1) Observe polymer solution pass through artificial core of water phase permeability 200x10⁻³µm² and 300x10⁻³µm² respectively, record the inlet and outlet pressure, convert pressure gradient.
(2) The injection rate of polymer solution remains constant [10] (0.2ml/min was taken in this experiment).
2.1.3. **Injection capability criteria.** According to the character of reservoir in the development zone, the comprehensive index for judging injection capacity was established (table 3).

**Table 3. Judgement index of injection capability**

| indicators | smooth | difficult | jam |
|------------|--------|-----------|-----|
| Maximum pressure gradient MPa/m | <2.5 | 2.5~3.5 | >3.5 |
| 0.05μm² | <1.5 | 1.5~2.5 | >2.5 |
| 0.1μm² | <1.0 | 1.0~1.5 | >1.5 |
| 0.2μm² | <0.7 | 0.7~1.0 | >1.0 |
| 0.3μm² | <0.4 | 0.4~0.7 | >0.7 |
| 0.4μm² |

2.1.4. **Experimental results.** The pressure gradient in the experiment was classified according to the relevant data measured in the experiment and the judgment index of injection ability (table 4). In the table, "difficulty" in injection was marked as light yellow, "jam" as dark yellow, and the rest as "smooth" injection (the same below).

**Table 4. Maximum pressure gradient table of polymers with different molecular weights passing through the core**

| permeability/ (10⁻³μm²) | concentration/ (mg/L) | Max. pressure gradient (MPa/m) | 16 million | 25 million |
|-------------------------|----------------------|-------------------------------|------------|------------|
| 200                     | 1000                 | Maximum pressure gradient<1  | 1.17       | 3.87       |
|                         | 1500                 | smooth.1 ~ 1.5 difficult>1.5 | 2.17       | 4.6        |
|                         | 2000                 | jams                          | 2.3        | 5.28       |
| 300                     | 1000                 | Maximum pressure gradient<0.7| 0.55       | 0.64       |
|                         | 1500                 | smooth.0.7 ~ 1.0 difficult>1.0| 0.61       | 0.68       |
|                         | 2000                 |                                | 0.69       | 0.74       |

From table 4, it can be seen that: At constant speed, it is difficult for 16 million molecular polymer to inject/plug 200x10⁻³ microns permeability core. For 300x10⁻³ microns permeability core is injected smoothly. 25 million molecular polymers are blocked to inject 200x10⁻³ microns permeability core. To inject 300x10⁻³ microns cores, it is difficult to inject only 2000mg/L at different concentrations. To sum up, at constant velocity of 0.2ml/min, 16 million and 25 million molecular polymers cannot inject 200x10⁻³ microns permeability layers, but the injection concentration must be taken into account.

2.2. **Constant pressure experiment**

Under constant polymer injection pressure, different molecular weight and concentration solutions were injected into cores with different permeability to observe the change of injection velocity and evaluate the injection effect.

2.2.1. **Experimental conditions.** Same as 2.1.1

2.2.2. **Experimental scheme.** ①16 million and 25 million molecular polymer solutions were injected to cores with water phase permeability ranging from 200x10⁻³ microns to 300x10⁻³ microns respectively. The injection rates were recorded at the beginning of the experiment, 0.1PV, 0.2 PV, 0.5 PV, 0.8 PV, 1.0 PV and 1.5 PV.
The pressure gradient was 0.15MPa/m and 0.10MPa/m. (according to the actual field data, the maximum pressure gradient at 120m injection-production well spacing can reach 0.15MPa/m, and the maximum pressure gradient at 150m injection-production well spacing can reach 0.10MPa/m. Therefore, pressure gradients of 0.15MPa/m and 0.10MPa/m are proposed to be used in the experiment.)

2.2.3. Injection capability criteria

\[ Q = VA\Phi \]  

Q—Injection flow, m³/d. V—Injection speed, m/d. A—Injection area, m². \( \Phi \)—porosity, %.

Under the condition of well spacing (120m), pressure gradient (0.15MPa/m), formation actual injection speed (2m/d), calculated by the type (1), corresponding to the laboratory core (Φ25×100mm, and the porosity 29.4%), injection rate should be 0.2ml/min, the 0.2ml/min as the injection criterion, greater than or close to 0.2ml/min for injection ability. Similarly, the core injection amount corresponding to 150m well spacing and pressure gradient 0.10MPa/m with the actual injection speed of 1m /d is 0.1ml/min, and the core injection capacity is considered as good if it is greater than or close to 0.1ml/min. To sum up, the standard for judging the injection capacity under constant pressure injection is: under the pressure gradient of 0.15mpa/m, if the injection speed is >0.190ml/min, the jam will occur. If the speed is <0.08ml/min, the jam will occur. If the speed is <0.18ml/min, the jam will occur. Under the pressure gradient of 0.10MPa/m, if the injection speed<0.090ml/min, the injection is considered to be smooth. If the injection speed is 0.180 ~ 0.190ml/min, it is considered difficult to inject. If the speed is <0.18ml/min, the jam will occur. Under the pressure gradient of 0.10MPa/m, if the injection speed<0.090ml/min, the injection is considered to be smooth. If the injection speed is 0.080 ~ 0.090ml/min, it is considered difficult to inject. If the speed<0.08ml/min, the jam will occur.

2.2.4. Experimental results. In the experiment, polymer solution injection has been carried out to the artificial cores with the permeability 200×10⁻³ microns and 300×10⁻³ microns at constant pressure gradient of 0.15 and 0.10MPa/m. The injection speed is shown in table 5.

| Permeability (10⁻³μm) | Actual spacing (m) | Pressure gradient (MPa/m) | Judgment | Molecular weight (million) | Injection speed (mg/L) | Injection speed (ml/min) |
|----------------------|--------------------|---------------------------|----------|---------------------------|-----------------------|-------------------------|
|                      | 120                | 0.15                      |          |                           |                       |                        |
|                      |                    |                           | Injection speed<0.190 | smooth.0.180 ~ 0.190 | 16                     | 1000 0.894 0.622 0.427 0.204 0.211 0.22 0.207 0.174 0.177 0.172 0.172 |
|                      |                    |                           | difficult.<0.18      |                | 2000 0.753 0.500 0.201 |                        |
|                      | 150                | 0.1                       |          |                           |                       |                        |
|                      |                    |                           | Injection speed<0.090 | smooth.0.080 ~ 0.090 | 16                     | 1000 0.846 0.570 0.399 0.204 0.209 0.199 0.198 0.198 0.198 0.198 0.198 |
|                      |                    |                           | difficult.<0.08      |                | 2000 0.701 0.466 0.204 0.164 0.159 0.162 0.162 0.162 0.162 0.162 0.162 |
|                      | 300                | 0.15                      |          |                           |                       |                        |
|                      |                    |                           | Injection speed<0.190 | smooth.0.180 ~ 0.190 | 16                     | 1000 0.861 0.630 0.357 0.170 0.205 0.208 0.209 0.209 0.209 0.209 0.209 |
|                      |                    |                           | difficult.<0.18      |                | 2000 0.687 0.433 0.209 0.155 0.161 0.157 0.161 0.161 0.161 0.161 0.161 |
|                      | 150                | 0.1                       |          |                           |                       |                        |
|                      |                    |                           | Injection speed<0.090 | smooth.0.080 ~ 0.090 | 16                     | 1000 0.827 0.605 0.343 0.163 0.197 0.192 0.184 0.184 0.184 0.184 0.184 |
|                      |                    |                           | difficult.<0.08      |                | 2000 0.646 0.407 0.196 0.148 0.151 0.148 0.151 0.151 0.151 0.151 0.151 |

From the data in table 5, it can be seen that 16 million molecular polymers ranging from 1000mg/L to 1500m/L will not be blocked to the 200×10⁻³μm² layer. It is difficult/blocked to inject 2000mg/L and 16 million molecular polymers. When the polymer is injected with a concentration of 1000mg/L and 25 million molecular, it is smooth. When the concentration is 1500 ~ 2000mg/L, the injection is
difficult/blocked, it cannot be injected. To the 300×10⁻³µm² layers, inject 16 and 25 million molecular polymers, concentration of 1000 ~ 2000mg/L are smooth.

In conclusion, by comparing the condition of 1000 ~ 2500mg/L, 1600 and 25 million mg/L of polymer injection of the constant speed or constant pressure, it can conclude that (1) in general, 200×10⁻³µm² permeability, under the condition of constant pressure injection, low concentration polymer injection can be smoothly, in the condition of constant speed polymer injection can be difficultly, constant speed injection is more favorable in choice. 300×10⁻³µm² permeability, in addition to 25 million and 2000mg/L polymer constant speed injection difficult, constant speed or constant pressure injection of other molecular concentration polymer is smooth. 200×10⁻³µm² permeability core, under constant pressure injection conditions, 2000mg/L of 16 million and 25 million molecules are blocked. Therefore, injection concentration 1000 ~ 1500mg/L (16 million molecules), 1000 mg/L (25 million molecules) is recommended.

3. Conclusion

(1) at constant velocity of 0.2ml/min, 16 million and 25 million molecular polymers cannot inject 200×10⁻³µm² permeability layer.
(2) 200×10⁻³µm² permeability core, in 0.1 and 0.15 MPa/m constant pressure injection conditions, according to the experimental congestion, the recommended concentration of polymer injection is 1000 ~ 1500mg/L (16 million molecules), 1000 mg/L (25 million molecules).
(3) 300×10⁻³µm² permeability, only 2000mg/L and 25 million molecular polymers in constant speed polymer injection is difficult, constant speed or constant pressure injection of other molecular concentration polymer is smooth.
(4) in 200×10⁻³µm² permeability, low concentration polymer can be injected smoothly in constant pressure injection, in constant speed injection it is difficult, constant speed injection is beneficial in changing polymer injection mode.

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