Newest progress of chemical flooding technique of PetroChina

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1. Introduction

2. Application of polymer flooding

3. Development of chemical combination flooding

4. Conclusions
By the end of 2008, the average water cut for main oil fields of PetroChina has been reached 85% and average recovery factor is 34.6%.

70% of recoverable reserve was produced.

Most oil fields were developed by water flood and recovery was low.

The remaining oil production relies on advanced technology like EOR.
Potential and application condition of chemical flooding

2/3 proven reserves will remain underground by conventional production technology.

Produced oil: $3.5 \times 10^9$ t

Unrecoverable: $9.7 \times 10^9$ t

Remains: $1.5 \times 10^9$ t

In 1987-1990 and 1997-1999, The EOR potential analysis for onshore oil field of China were curried out and scientific data was provided for the strategy of EOR application.
Potential and application condition of chemical flooding

Chemical flooding will be the most suitable method among EOR technology

<table>
<thead>
<tr>
<th>EOR Techniques</th>
<th>Suitable reserves (10^6t)</th>
<th>Incremental Recovery (%)</th>
<th>Incremental Reserves (10^6t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polymer</td>
<td>2905</td>
<td>9.7</td>
<td>282</td>
</tr>
<tr>
<td>Polymer/Alkali</td>
<td>141</td>
<td>13.1</td>
<td>18</td>
</tr>
<tr>
<td>Surfactant/Polymer/Alkali</td>
<td>3127</td>
<td>19.2</td>
<td>600</td>
</tr>
<tr>
<td>Gas (miscible)</td>
<td>525</td>
<td>18.2</td>
<td>95</td>
</tr>
<tr>
<td>Gas (immiscible)</td>
<td>702</td>
<td>8.7</td>
<td>61</td>
</tr>
<tr>
<td>Thermal</td>
<td>574</td>
<td>22.2</td>
<td>128</td>
</tr>
</tbody>
</table>

11.8 × 10^8 t recoverable reserves can be increased by EOR
Development of chemical flooding

Three stages

1960s to 1970s——Micromulsion flooding (Sa 3-15%)

1980s——Alkalin flooding, polymer flooding, activated water flooding (HPAM conventional Sa)

1990s——Combined flooding (synergic effect Sa <0.4%, salt-resistant polymer)

PetroChina
## Development of chemical flooding

### Enhanced oil recovery (EOR) potential of some chemical flooding techniques

<table>
<thead>
<tr>
<th>Types of EOR</th>
<th>Enhanced recovery, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkali flooding</td>
<td>2-8</td>
</tr>
<tr>
<td>Polymer flooding</td>
<td>7-15</td>
</tr>
<tr>
<td>Alkali-Polymer flooding</td>
<td>10-17</td>
</tr>
<tr>
<td>Alkali-Surfactant flooding</td>
<td>6-20</td>
</tr>
<tr>
<td>ASP flooding</td>
<td>15-25</td>
</tr>
<tr>
<td>Foam flooding</td>
<td>10-25</td>
</tr>
</tbody>
</table>
Outline

1. Introduction

2. Application of polymer flooding

3. Development of chemical combination flooding

4. Conclusions
Field application of polymer flooding

Current status of applications of polymer flood

<table>
<thead>
<tr>
<th></th>
<th>1996</th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blocks:</td>
<td>43</td>
<td></td>
</tr>
<tr>
<td>Area:</td>
<td>365.97km$^2$</td>
<td></td>
</tr>
<tr>
<td>No. of well:</td>
<td>4206</td>
<td></td>
</tr>
<tr>
<td>Injector:</td>
<td>1922</td>
<td></td>
</tr>
<tr>
<td>Producer:</td>
<td>2284</td>
<td></td>
</tr>
<tr>
<td>Polymer:</td>
<td>$860 \times 10^3$ t</td>
<td></td>
</tr>
<tr>
<td>Oil production:</td>
<td>$110 \times 10^6$ t</td>
<td></td>
</tr>
<tr>
<td>Incremental production</td>
<td>$48 \times 10^6$ t</td>
<td></td>
</tr>
<tr>
<td>Efficiency:</td>
<td>128t/t</td>
<td></td>
</tr>
</tbody>
</table>
Field application of polymer flooding

The Performances of the six Industrial applications

Fig. 1 The Water Cut of center well of the six Industrial applications
Field application of polymer flooding

Tab. 2 Parameters and results of three typical blocks of industrial polymer flooding tests

<table>
<thead>
<tr>
<th>Projects</th>
<th>Spacing (m)</th>
<th>Cp (mg/l)</th>
<th>Mw ($10^4$)</th>
<th>EOR (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DQ-L1</td>
<td>212</td>
<td>1002</td>
<td>1700</td>
<td>13.8</td>
</tr>
<tr>
<td>DQ-X5</td>
<td>200</td>
<td>1207</td>
<td>1500</td>
<td>14.6</td>
</tr>
<tr>
<td>DG-B4</td>
<td>200</td>
<td>1500</td>
<td>2000</td>
<td>11.5</td>
</tr>
<tr>
<td>Means</td>
<td>206</td>
<td>1236</td>
<td></td>
<td>13.3</td>
</tr>
</tbody>
</table>
Field application of polymer flooding

Ten integrated techniques for polymer flooding

1. Polymer screening and evaluation
2. Scenario design and numerical simulation
3. Low shear well completion
4. Low viscosity loss facility of injection
5. Produced liquid handling
6. Monitoring technique
7. Protecting partially abrasion for Lifting technique
8. Separate zone injection
9. Profile modification prior to polymer flooding
10. Prediction and economic evaluation
Supply of polymer can meet the requirement for EOR and new type polymer emerged continuously.

Polymer used for EOR purpose is currently be manufactured domestically and appearance of new type polymer enhances the properties and also decreases the cost. It provides a solid basis for application of polymer flooding.
1. Introduction
2. Application of polymer flooding
3. Development of chemical combination flooding
4. Conclusions
Development of chemical combination flooding

The types of combination flooding through the combination of three chemicals
the main types of chemical combination flooding techniques in practical field application are as follows:

- alkali-polymer binary flooding (AP)
- alkali-surfactant-polymer combination flooding (ASP)
- surfactant-polymer binary flooding (SP)
Development of chemical combination flooding

Characteristic of alkali-polymer binary flooding (AP flooding)

1. Alkali can react with the organic acids or organic acid components in the crude oil to in-situ form interfacial active materials, which can decrease the o/w IFT and increase oil displacement efficiency.
2. Alkali can change the electric property of rock surface and decrease the adsorption of polymer on rock.
3. Alkali can change the wettibility of rock surface from oil-wet to water wet which is helpful for removing the residual oil.
4. The addition of polymer increases the viscosity of solution and decreases the mobility ratio of solution to oil so as to improve swept efficiency.
5. Useally strong alkali like NaOH is used.

The concentration of alkali is high and the use of strong alkali leads to certain damage of reservoir. Large dosage of alkali has bad effect on the viscosity of SP binary formula.
Characteristic of alkali-surfactant-polymer combination flooding (ASP)

① The synergistic action of alkali and surfactant in ASP flooding can effectively decrease o/w IFT and improve oil displacement efficiency. The addition of polymer increases the viscosity of solution so as to improve swept efficiency.

② The concentration of surfactant in ASP flooding is lower than 0.4%wt.

③ The alkali in ASP flooding can be strong alkali and weak alkali.

④ ASP flooding technique is suitable for high acid value crude oil. It also suitable for crude oil with low or even zero acid value.

The major problem in ASP flooding technique is that in the strong alkali ASP system, scaling and emulsification bring problems in lifting and produced liquid treatment.
Characteristic of surfactant-polymer combination flooding (SP flooding)

① Surfactant is used to decrease o/w interfacial tension to increase oil displacement efficiency. polymer is added to increase the viscosity of displacement liquid to improve swept efficiency.

② The concentration of surfactant in SP flooding is lower than 0.4%wt.

③ SP flooding technique is suitable for high acid value crude oil. It also suitable for crude oil with low or even zero acid value.

④ The elimination of alkali can avoid damage of combination flooding to reservoir. The side effects of scaling, emulsification and corrosion on lifting craft and produced liquid treatment can also be prevented. The concentration of polymer in the alkali-free SP flooding can be decreased. The main challenge in the SP flooding technique is that it requires high interfacial performance surfactant.
Remarkable results were obtained through field practices and incremental recovery was about 20% higher than water flooding.

It makes ASP flooding a new technique after polymer flooding.

### Table 4  Pilot tests of ASP combination flooding in PetroChina

<table>
<thead>
<tr>
<th>Project</th>
<th>Lithology</th>
<th>Injector/producer</th>
<th>Spacing m</th>
<th>ASP</th>
<th>EOR (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DQ-X5-P</td>
<td>Sand</td>
<td>1/4</td>
<td>141</td>
<td>NaOH/ORS-41/HPAM</td>
<td>25.0</td>
</tr>
<tr>
<td>DQ-X2-D</td>
<td>Sand</td>
<td>4/9</td>
<td>200</td>
<td>NaOH/ORS-41/HPAM</td>
<td>19.40</td>
</tr>
<tr>
<td>DQ-B1X-D</td>
<td>Sand</td>
<td>6/12</td>
<td>250</td>
<td>NaOH/ORS-41/HPAM</td>
<td>20.63</td>
</tr>
<tr>
<td>DQ-XJJ-P</td>
<td>Sand</td>
<td>3/4</td>
<td>75</td>
<td>NaOH/MS/HPAM</td>
<td>23.24</td>
</tr>
<tr>
<td>DQ-ZQX-P</td>
<td>Sand</td>
<td>4/9</td>
<td>106</td>
<td>Na2CO3/B-100/HPAM</td>
<td>21.4</td>
</tr>
<tr>
<td>XJ-ZH2-P</td>
<td>Conglomerate</td>
<td>4/9</td>
<td>50</td>
<td>NaOH/KPS/HPAM</td>
<td>24.5</td>
</tr>
</tbody>
</table>
Industrial field practices proved the high incremental recovery of ASP flooding.

New surfactant is under testing with weak alkaline ASP flooding.

Target reservoir is expanded from type I reservoir to type II reservoir.

Filed tests of alkali-free SP combination flooding have been planned in Jilin, Liaohe and Xinjian oilfield.
Performance of APS pilot test

EOR = 19.5%

Water cut (%)

Recovery (%)

0 0.2 0.4 0.6 0.8

Accumulative PV

Former polymer slug  ASP main slug  ASP slug  Polymer slug  Water flooding
Development of chemical combination flooding

Performance of APS pilot test

Change of Overall water cut in the central well zone

Water flooding: 95.4%
ASP flooding: 69.1%
Decreased 26.3%
Challenge in the application

1. Scaling and emulsification occur in strong alkali ASP flooding pilot test
2. Development of new surfactant for SP system
3. New polymer products suitable for Type II reservoir
4. New oil-displacing agent for high temperature and high salinity
5. Multi-function surfactant for low permeability reservoir
   (Scaling preventing, corrosion inhibiting, low interfacial tension, wettability alteration)
Conclusions

1. Polymer flooding technique has been applied in industrial expansion blocks of PetroChina. The average enhanced oil recovery on the basis of water flooding of three typical blocks is 13.9%. Ten integrated techniques have been achieved in the research and application of polymer flooding. Presently polymer flooding is being expanded to conglomerate reservoirs and fault block reservoirs with the development of technique. It plays an important role in the maintenance of crude oil production of PetroChina.
2. Magnificent enhancement of recovery has been achieved in the pilot tests of ASP combination flooding. ASP flooding technique begin to enter industrial application stage. Chemical combination flooding technique will be one of the dominating EOR techniques to be expanded in the next stage.

3. The chemical combination flooding changes from strong alkali ASP flooding to weak alkali ASP flooding to alkali-free combination flooding. The application reservoir object expands from type I reservoir to type II reservoir and from integral sandstone reservoirs to conglomerate reservoir and to complicated fault block reservoirs.
Thanks