Hearing How Preformed Particle Gels Can Control Water Production in Mature Oilfields

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Outline

• What is Preformed Particle Gel (PPG)
• Importance of Gel Treatment for Water Production Control
• A Few Questions Often Being Asked for PPG Treatment
• Case Studies of Field Applications
• Lessons Learned from More Than 5,000 PPG Treatments
• Summary
• Acknowledgement
What is Preformed Particle Gel (PPG)

• Cross-linked polyacrylamide powder, Super Absorbent Polymer
• Size ranging from nano-meter to millimeter
Importance of Gel Treatment for Water Production Control in Mature Oilfields

• Excess water production is the most serious problem to reduce oil production as oilfields are maturing.

• The total cost to separate, treat, and dispose of water is approximately $50 billion per year.

• Gel treatments are often one best choice to mitigate channeling through fractures and super-K streaks.

• Gel treatment is one of cost-effective methods to improve sweep efficiency.
Gel Treatments to Block/Reduce Water Flow through High Permeability Zone/Streak

• Near Wellbore Problems
  – High-permeability matrix-rock strata without crossflow

• Far-wellbore Reservoir Problems

(a) Vertical heterogeneity with crossflow
(b) High permeability streaks
(c) Fracture channeling
(d) Solution channels
Gels Used for Conformance Control

- In-situ gel systems: Gelant is injected into formation and gel is formed under reservoir conditions after placement. Gelation occurs in the reservoir.

- Preformed gel systems: Gel is formed in surface facilities before injection, and then gel is injected into reservoirs. No gelation occurs in reservoir.
## Current Preformed Particle Gel Systems

<table>
<thead>
<tr>
<th>Name</th>
<th>Developer</th>
<th>Particle Size</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bright Water®</td>
<td>Chevron, BP and Nalco (Tirco)</td>
<td>Sub-Micro (&lt; 1 µm)</td>
<td>60+ injectors</td>
</tr>
<tr>
<td>Microgel</td>
<td>IFP</td>
<td>Micro (1-10 µm)</td>
<td>10+ producers</td>
</tr>
<tr>
<td>PPG</td>
<td>PetroChina MS&amp;T Halliburton</td>
<td>Millimeter (10 µm to millimeters)</td>
<td>5,000+ Injectors in China</td>
</tr>
<tr>
<td>pH Sensitive polymer</td>
<td>UT</td>
<td>Micro</td>
<td>Not reported</td>
</tr>
</tbody>
</table>
A Few Questions Often Being Asked for PPG Treatment

Q1. Why using particle gels for conformance control?

Q2. Why developing millimeter-sized particles at very beginning?

Q3. Can mm-sized particles propagating through md-level formation?

Q4. Can particle gels fully block open fractures, voids, and conduits?
Q1. Why Particle Gels For Conformance Control

• Inherent disadvantages of In-Situ Gel

  Crosslinking reactions and gel quality are strongly affected by
  – Shear of pump, wellbore and porous media
  – Adsorption and chromatography of chemical compositions
  – Dilution of formation water

• Particle gel is deformable and easier to transport through porous media than Hard particle.

• Single component and easy operation in oilfields
Q2: Why using mm-sized (>10µm) particle gels?

- Fractures or high-permeability streaks/channels exist extensively in mature water-flooded reservoirs.
- Millimeter-sized PPGs can preferentially enter into fractures or fracture-like channels/conduits while minimizing gel penetration into low-permeability zones/matrixes.

Water Flooding

Polymer Flooding

In-situ gel treatment

Nano-particles

Mm-size particles gel treatment

- More polymer enters low-K zones comparing to W.F.
- More polymer needs to be used.
Q3: Can mm-sized propagate mD porous media?

- Millimeter sized particles cannot penetrate into the porous media with a permeability less than 1000 md.
- If particle size and strength are appropriate, no non-permeable cakes can be formed on the surface of rocks.

![Graph showing permeability reduction (%)](image)

Large particles cannot damage conventional permeable rocks

Core surface after PPG injection
(a) No damage
(b) Cake but can be flushed out.
Q3. Can mm-sized propagate mD porous media?

- If the particles are weak, mm-sized PPGs would form a cake rather than penetrating into the cores.
  
  (1) Crossflow reduce the negative effect

(2) Acid soak near wellbore to remove cake (SPE172352)
A Reservoir with Fracture(s) or Super-K Channels
A Reservoir without fractures or Super-K Channels

Trial and Error Technique
Q4: Can particle gels fully block open fractures, voids, and conduits?

- Particle moved piston-like in open fractures and formed permeable *Gelpack*.
- The permeability of *Gelpack* can be a few hundreds to a few thousands of md, depending on gel strength, particle size and flow rates.
Particles moved piston-like and formed *GelPack*

Gel movement during PPG injection

(t = 0.2 PV)

(t = 1.5 PV)

(t = 2.5 PV)

(t = 3.2 PV)

Gel Particles is a fracturing-filling material. Particles will form a particle pack in open fracture/fracture-like features.
Brine Created Channels and Flowed in *GelPack*

Brine movement during brine injection into Permeable *GelPack* in the fracture

PPG cannot fully block open fractures but forms permeable *GelPack* of which permeability can be controlled by particle strength and sizes
Field Applications

- More than 5,000 applications in China and other countries.
- PPG treatment has been successfully applied in:
  - Water flooding mature reservoirs without natural fractures or intentionally hydraulic fractures
  - Fracture reservoirs
  - High temperature (up to 130°C) high salinity (30%) reservoirs
  - CO\textsubscript{2} Flooding Reservoirs
  - Polymer Flooding wells
  - ASP Flooding wells
- PPG weight: 6,600 ~88,000 lbs/well, commonly 17,600-33,000 lbs per well
Case 1: First Pilot in Daqing, PetroChina

- Well No and Location: X7-2-F24
- Formation brine salinity: 4,500 mg/L
- Temperature: 40 °C
- Reservoir type: Sandstone without natural fractures or intended hydraulic fractures
- Permeability: Recorded maximum permeability is 1,200 md.
Case 1: First Pilot in Daqing, PetroChina

• Reservoir Heterogeneity
  – Vertical Heterogeneity (Injection profile): only 1/5 perforated zone absorbed water
Case 1: First Pilot in Daqing, PetroChina

• Treatment Design
  – PPG amounts: 34,100 lbs
  – PPG suspension: 3,000 m³ PPG suspension using produced water
  – PPG Properties:
    • Size: 1.5 mm, 3 mm, and 5 mm
    • Swelling ratio: 60~80 times
    • Stability: no dehydration within 2 years
  – Injection method: PPG Suspension alternated with produced water
Case 1: First Pilot in Daqing, PetroChina

Injection scheme (facilities)
Case 1: First Pilot in Daqing, PetroChina

Injection performance– multiple stages

<table>
<thead>
<tr>
<th>Stage</th>
<th>Conc (%)</th>
<th>Size (mm)</th>
<th>Vol (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>1.0</td>
<td>5</td>
<td>100</td>
</tr>
<tr>
<td>2nd</td>
<td>0.5</td>
<td>1.5</td>
<td>600</td>
</tr>
<tr>
<td>3rd</td>
<td>0.5</td>
<td>3</td>
<td>1700</td>
</tr>
<tr>
<td>4th</td>
<td>0.5</td>
<td>5</td>
<td>600</td>
</tr>
</tbody>
</table>

Water alternated PPG injection
Case 1: Results from First Pilot in Daqing

- Water injection pressure: increased from 5.0 to 8.2 MPa.
- Oil production: 17,500 bbl of increased Oil within 7 months.
- Injection profile: Water absorption zone thickness from 11.5 m to 21.5 m.
Case 2: PPG Application in High Salinity High Temperature Water Flooding Reservoirs

Reservoir Conditions:

- Sandstone without natural fractures or intended hydraulic fractures
- Formation temperature: 125 °C (257°F)
- Formation salinity: $23 \times 10^4$ ppm
- Permeability: 0.23 D
- Tracer test: 60 d breakthrough

Reason for treatment: High-permeability channels exist
Case 2: PPG Application in HSHT Reservoirs

Treatment:

- Treated wells: 4 injection wells
- PPG amounts: 375,782 lbs (93,946 lbs/well)
- PPG suspension: 69,260 m³ (17,315 m³/well)

PPG properties:

- Size: 28 μm~1 mm
- Swelling ratio: 15~25 times
- Stability: no dehydration within one year
- High temperature (284 °F) and salinity resistance (23%)
Case 2: PPG Application in HSHT Reservoirs

Injection Pressure Monitoring Results

PPG injection Curve for Well 4
Case 2: PPG Application in HSHT Reservoirs

Drawdown Test for Injection Well 4

Pressure drawdown test for Well 4

Pressure (psi) vs. Time (90 min)

- 2nd slug
- 3rd slug
- 4th slug
- 5th slug
- after treatment
- before treatment
Case 2: PPG Application in HSHT Reservoirs

Decline Curve for 9 Production Wells

Before Treatment

After Treatment

<table>
<thead>
<tr>
<th>Increased Oil</th>
<th>204,188 bbl</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil incr. per PPG</td>
<td>170.5 t/t</td>
</tr>
</tbody>
</table>

27,971 t
Case 3: PPG Application in Polymer Flooding

Reservoir Conditions:
- Sandstone with natural fracture
- Temperature: 33°C (91.4°F)
- Salinity: 5600~5700 ppm
- Permeability: 0.16 D

Reason for treatment:
- Polymer early breakthrough
PPG Application in Polymer Flooding

Polymer concentration for 18 production wells
Lessons Learned from Field Application Results

• Fracture or fracture-like channels widely exists in mature oilfields *but it has not been recognized by those engineers without field experience.*

• No injectivity problem was found for most treatments even though these reservoirs have no natural fractures or intentionally hydraulic fractures.

• “Trial and Error” technique can be used for better gel treatment results

• Negative effect was rarely found.

• PPG treatment is a simple and cost-effective method to control water production.
Summary

- PPGs have been successfully synthesized in commercial scale and applied in mature oilfields to control water production.
- PPG strength and size are controllable. It can overcome some distinct drawbacks inherent to in-situ gelation systems.
- Swollen PPG forms a gel-pack after placement in a fracture, and the gel-pack permeability can be controlled by particle size and strength.
- Millimeter-sized (10 µm-mm) PPGs have been successfully applied in more than 5000 wells without injectivity problems.
- Trial and Error method can be used for mm-sized PPG treatments.
- PPG treatment is a simple and cost-effective method to control conformance for water and polymer flooding.
Acknowledgements
Selected Journal Publications for Particle Gels

1. Imqam, A.**; Elue, H.; Bai, B.*, Hydrochloric Acid Applications to Improve Preformed Particle Gel Conformance Control Treatment, *SPE Production*. (in revision)


Thanks!

Questions?

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Facilities to Pump PPG

- Large amount of PPG injection for multiple wells
- The second largest chemical EOR technology after polymer flooding in China
- Field-wide application rather than single well treatment
Facilities to Pump PPG

Picture of PPG Injection Site
Facilities to Pump PPG

Picture of PPG Injection Site
Q4: Do we need control swelling rate if we only consider injectivity?

The more swelling, the more deformable
Experiment Descriptions

- **PPG size (dry):** ~ 0.6 mm
- **Tubes ID:** 10.922, 3.048, 1.752, and 0.774 mm
- **Brine Concentrations:** 0.05, 0.25, 1, and 10%

![Swelling Ratio Chart]

![Gel strength Chart]
Conduit Experiment: Methodology and Experiment
PPG Injection Pressure

- Gel injection pressure (psi)
- Gel injection velocity (ft/day)
- Conduit opening size 3.048 mm

Lines represent different concentrations:
- Purple: 0.05%
- Green: 0.25%
- Red: 1%
- Blue: 10%
- Fully Swelling Particles have better Injectivity than Partially Swelling Particles
- Particle strength is more dominant for particle movement than particle size
PPG Resistance to Water Flow

- Conduit opening size 1.75 mm
- Conduit opening size 3.048 mm
- Conduit opening size 10.92 mm
A Swollen Particle Transport through a Throat

a. PPG moving to throat

b. Losing water from PPG front

c. Elongated particle filling throat

d. Particle through throat
A Process of a Particle through Throat(s)

a. PG was moving to throat.
b. PG was broken into two particles
c. Bigger part tried to pass through throat
d. PG become more arched
e. Two ends of PG enter two throats
f. PG was broken again and passed through throat
Transport Mechanism of a Particle through a Throat Smaller its Size

1. Deformed & elongation
2. Dehydrated
3. Broken