Polymer Simulator in OPM

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Content

• Polymer flooding introduction
• Polymer simulation model
• Current polymer simulator status
• Examples
• The way forward
Motivation

• Currently, Statoil uses Eclipse and CMG STARS.

• These simulators are proprietary.

• A platform for testing new algorithms and functionalities.

• Share the modern reservoir simulator infrastructure.
Polymer Flooding - Introduction

- Large polymer molecules
- Reduced water mobility
- Improved sweep

\[ \lambda_p = \frac{k_{rp}}{\mu_p} \]

- Increased water viscosity
- Accelerated recovery
- Macroscopic sweep improvement

Retention effects (adsorption, entrapment)

Reduced water relative permeability
EOR by Polymer Flood - Targets

- Reduce SOR
- Change wettability: ?
- Viscoelastic effects: ?
- Reduce M
  - Reduce $K_w$: Yes
  - Increase $\mu_w$: Yes
  - Increase $K_o$: No
  - Decrease $\mu_o$: No

$$f_w(S_w) = \frac{1}{1 + \frac{1}{M}}$$

$$M = \frac{k_{rw} / k_{ro}}{\mu_w / \mu_o}$$
## Polymer Flooding – Important parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity</td>
<td>Dependent on polymer concentration and shear rate. Rheology --- shear thinning or shear thickening</td>
</tr>
<tr>
<td>Adsorption</td>
<td>Unit: $\mu$g/g rock</td>
</tr>
<tr>
<td>RRF</td>
<td>Residual resistance factor or residual permeability reduction factor</td>
</tr>
<tr>
<td>IPV</td>
<td>Inaccessible pore volume</td>
</tr>
<tr>
<td>Mixing</td>
<td>Water and polymer mixing, Todd-Long staff model</td>
</tr>
</tbody>
</table>

### Rheology

![Rheology Graph](attachment: rheology_graph.png)

The rheology equation is given by:

$$ y = 254.58x^{-0.565} $$
Non-Newtonian Behavior

\[ \mu = k \cdot \gamma^{n-1} \]

\[ \mu_{sh} = \mu_{w, \text{eff}} \left[ \frac{1 + (P - 1)M}{P} \right] \]
Degradation effects

- Degradation effects for different injection rate and temperature
Mathematical model

\[
\frac{d}{dt}\left(\frac{V^* S_w C_p}{B_r B_w}\right) + \frac{d}{dt}\left(V p_r C_p^a \frac{1 - \phi}{\phi}\right) = \sum \left[\frac{T k_{rw}}{B_w \mu_p \text{eff} R_k} (\delta P_w - \rho_w g D_z)\right] C_p + Q_w C_p
\]

\[
V^* = V (1 - S_{dpv})
\]

\[
R_k(c^a) = 1 + \frac{\text{RRF} - 1}{\text{max_ads}} c^a
\]

\[
\mu_{p,\text{eff}} = \mu_m(c)^\omega \mu_p^{1-\omega}
\]

\[
\frac{1}{\mu_{w,\text{eff}}} = \frac{1 - c/c_{\text{max}}}{\mu_{w,e}} + \frac{c/c_{\text{max}}}{\mu_{p,\text{eff}}}
\]

\[
\mu_{w,e} = \mu_m(c)^\omega \mu_w^{1-\omega}
\]
Current status

- Fully implicit blackoil (water-oil) + polymer simulators, flow_polymer, ready for use.
- Water-oil-polymer simulators based on operator splitting algorithm.
- Same functionalities with Eclipse except thermal degradation.
  - IPV
  - Adsorption
  - Permeability reduction
  - Mixing Parameter
  - Non-Newtonian behavior (by Kai Bao)
Example-SAIGUP study

- 96000 cells
- Permeability distribution
- 10 Wells
Well results
Example--3D with shear effects

• Properties

- PORO
- Initial pressure
- Initial Oil saturation
- Initial Gas saturation

• Initial distribution

- PERMX(md)
- PERMZ(md)
- Initial Water saturation

PROD01, INJE01, PROD02
Shear effects
Shear-thickening
Shear-thinning
The way forward

• Performance
• Degradation model
• Injectivity calculator
• Core-flooding?
Thank you!
There’s never been a better time for good ideas