Updates on Reservoir Simulation

Prepared for the EORI Joint EOR Commission & Technical Advisory Board Meeting

Shaochang Wo
EORI, University of Wyoming

Denver, January 15, 2009
Grieve Field: completed
Fiddler Creek Field: completed
Hat Field: ongoing
Mahoney Dome Field: ongoing
Field in Powder River Basin: ongoing
It Takes A Team

- John Lorenz, Peigui Yin & Mark Tomasso
  - Fractured reservoir characterization
  - Petrography and petrophysics
  - Geologic modeling
- Norman Morrow & Xina Xie
  - Reservoir rock wettability analysis
- Hertanto Adidharma
  - Slim-tube experiments for CO₂-oil MMP
- Students
  - Michael Presho & Matthew Johnson
15-node HP cluster (Dec. 2006), each code has dual processors, with a 4TB NetApp data storage

30 Eclipse Parallel licenses ($26 million software donation from Schlumberger)

Eclipse package including BlackOil, Compositional, Thermal, and FrontSim simulators

Petrel 2008 (Schlumberger) for building static reservoir (matrix & fracture) models, exported into Eclipse format
Evaluation of Gravity Stable CO2 Flooding in the Muddy Reservoir of Grieve Field

- The reservoir is a stratigraphic/structural trap with an average structural dip of 15°
- A 4-layer full-field model was created in Petrel and exported to Eclipse format
- A black-oil model was used for history match and a 9-component compositional model was used for CO2 flooding forecast
- More than 20 scenarios were simulated under different CO2 injection volumes and well configurations
<table>
<thead>
<tr>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Targeted Oil in Place, MMSTBO</strong></td>
<td>37</td>
<td>37</td>
</tr>
<tr>
<td><strong>Repressurization Phase</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO2 injection wells</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Per-well CO2 injection rate, mscf/day</td>
<td>5,000</td>
<td>11,000</td>
</tr>
<tr>
<td>Total CO2 injection rate, mscf/day</td>
<td>50,000</td>
<td>110,000</td>
</tr>
<tr>
<td>CO2 volume factor, rb/mscf</td>
<td>0.42 - 0.54</td>
<td>0.42 - 0.54</td>
</tr>
<tr>
<td>Total CO2 injected, bscf</td>
<td>109.5</td>
<td>110.4</td>
</tr>
<tr>
<td>Injected CO2 slug size, PORV</td>
<td>0.35</td>
<td>0.35</td>
</tr>
<tr>
<td>CO2 injection duration, years</td>
<td>6</td>
<td>2.75</td>
</tr>
<tr>
<td><strong>Production Phase</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO2 injection wells</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Per-well CO2 injection rate, mscf/day</td>
<td>5,000</td>
<td>11,000</td>
</tr>
<tr>
<td>Total CO2 injection rate, mscf/day</td>
<td>15,000</td>
<td>44,000</td>
</tr>
<tr>
<td>CO2 volume factor, rb/mscf</td>
<td>0.42 - 0.54</td>
<td>0.42 - 0.54</td>
</tr>
<tr>
<td>Total CO2 injected, bscf</td>
<td>125</td>
<td>421.1</td>
</tr>
<tr>
<td>Injected CO2 slug size, PORV</td>
<td>0.4</td>
<td>1.35</td>
</tr>
<tr>
<td>Production wells</td>
<td>10</td>
<td>14</td>
</tr>
<tr>
<td>Total oil produced, mmbo</td>
<td><strong>19.8</strong></td>
<td><strong>22.2</strong></td>
</tr>
<tr>
<td>Maximum daily oil rate, stbo/day</td>
<td>8,300</td>
<td>12,380</td>
</tr>
<tr>
<td>Total gas produced (including CO2), bscf</td>
<td>107.7</td>
<td>392.5</td>
</tr>
<tr>
<td>Maximum daily gas rate, mscf/day</td>
<td>40,000</td>
<td>109,000</td>
</tr>
<tr>
<td>Total water produced, mmbw</td>
<td>19.2</td>
<td>22.1</td>
</tr>
<tr>
<td>Maximum daily water rate, bw/day</td>
<td>11,600</td>
<td>14,500</td>
</tr>
<tr>
<td>Injection/production duration, years</td>
<td>24</td>
<td>27.25</td>
</tr>
<tr>
<td><strong>Overall CO2 Usage of Both Phases</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO2 injected, bscf</td>
<td>234.5</td>
<td>531.5</td>
</tr>
<tr>
<td>CO2 produced &amp; reinjected, bscf</td>
<td>89</td>
<td>360.8</td>
</tr>
<tr>
<td>CO2 purchased, bscf</td>
<td>145.5</td>
<td>170.7</td>
</tr>
<tr>
<td>Net CO2 utility, mscf/bo</td>
<td>7.35</td>
<td>7.69</td>
</tr>
<tr>
<td><strong>Overall Operation Duration, years</strong></td>
<td>30</td>
<td>30</td>
</tr>
</tbody>
</table>
The reservoir is divided into two operating units and reservoir flow is largely dominated by fractures.

Simulation of CO2 WAG flooding was performed on various sector models that represent possible flooding patterns in the reservoir.

For each unit, a representative sector model was selected after compared with the unit historical waterflood performance.

Dimensionless curves of incremental oil versus injected WAG volume were derived from the representative sector models and applied to evaluate the unitwide performance of CO2 flooding.
West Fiddler Creek Unit: Evaluated Scenario of CO2 WAG (1:1) Flood (with 24% of injection loss)
East Fiddler Creek Unit: Evaluated Scenario of CO2 WAG (1:1) Flood
(with 16% of injection loss)
Modeling and Simulation of the Fracture-Dominated Tensleep Reservoir at the Hatfield

- As part of our ongoing study of Tensleep fractures and their effect on reservoir flow
- Related studies performed at EORI:
  - Fracture characteristic in cores, John Lorenz
  - Core petrography and log correlation, Peigui Yin
  - Digitizing of production data, Matt Johnson
  - Fracture volume estimation and modeling the uncertainty of fracture cementation, Michael Presho
  - Core wettability tests, Xina Xie
WELL GOVT-5
Most fractures filled with calcite cement

WELL UPRR-2
Numerous open fractures propped by large calcite crystals

WELL UPRR-3
A small number of open fractures with narrow apertures

WELL UPRR-5
Most fractures filled with calcite cement
Dual Porosity Model of A Fracture System

- Storage Fractures
- Conductive Fractures (<10%)

Number of Fractures vs. Open Fracture Size
Modeling and Simulation of the Fracture-Dominated Tensleep Reservoir at the Hatfield

- A Petrel fracture model based on the fracture sets and intensity from the core study
- A dual-porosity/single-permeability simulation model for the Hatfield Tensleep reservoir
  - Dual porosity: matrix + storage fractures; conductive fractures
  - Single permeability: conductive fracture only
- Tuning the model to match the historical production and estimating the distribution of conductive open fractures
Evaluation of CO2 Flooding in the Tensleep Reservoir of Mahoney Dome Field

Mahoney Dome: Estimated Permeabilities From Well Productions

- Estimated Permeability from Production (with Well Number)
- Average Permeability from Log Correlation
Current Research Topics

- Flow in fractured reservoirs
  - Fracture characterization and modeling
  - Estimation of fracture permeability distribution from regression of production and well tests
- Optimization of CO$_2$ floods at field-scale
  - Gravity stable CO$_2$ injection
  - CO$_2$ WAG flooding
- Equation of state (EOS) tuning to predict the phase behavior of CO$_2$-oil mixtures
Potential Application of Fly Ash in Injection Profile Control and EOR Flooding

Prepared for the EORI Joint EOR Commission & Technical Advisory Board Meeting

Shaochang Wo and Peigui Yin
EORI, UW

Ligang Yu, Xuanji Zhang, Xina Xie and Norman Morrow
Chemical & Petroleum Engineering Dept., UW

Denver, January 15, 2009
2007 Average Water Cut from Wyoming Oil Producing Reservoirs is 96.9%
Mechanisms of Particle Capture by Porous Media

Big Particles

Medium Particles

Small Particles

SURFACE CAKE

STRAINING

DEPOSIT
Characteristics of Fly Ash Particles

- Collected from the chimneys of coal-fired power plants by electrostatic precipitators or filter bags
- Generally spherical in shape
- Particle size: 0.5~300 μm
- True density: 2~2.3 t/m³
- Packing density: 550~658 kg/m³
- Packing porosity: 60%~75%
Two classes of fly ash are defined by ASTM C618: Class F fly ash and Class C fly ash. The chief difference between these classes is the amount of calcium, silica, alumina, and iron content in the ash.

In Wyoming, Class C fly ash (high in calcium) is produced from subbituminous and lignite coals from the Powder River basin. Class F fly ash (low in calcium) is produced from bituminous and subbituminous coals in the Green River basin.
Western Region Fly Ash Survey
Potential Application of Fly Ash in EOR

- For Improving Water Injection profile
  - Fly ash + polymer
  - Fly ash + polymer + coagulant
- For Use in Combination with
  - CO2 flooding
  - Surfactant flooding
  - Steam flooding
Proposed Works

- Identifying suitable fly ash sources (prefer from Wyoming power plants)
- Searching for applicable oil reservoirs in Wyoming as potential testing sites
- Purchasing of needed lab equipments
- Lab flooding tests for selected cores and fly ash samples
- Modeling of fly ash migration and straining in porous media and fractures
- Design of fly ash injection for a pilot testing site