WCSFD of an urban waterflood oil field

Yowlumne Field

PTE 555 Term Project Presentation
July 31st, 2014

Team 7

Watanapong Ratawessanan
Team Leader
Scott Dorman
Well Completion
Ege Senkutlu
Formation Damage
Nithin Thomas John
Stimulation
Presentation Outline

• Field Background
• Strategy and Given
• Well Completion
• Formation Damage
• Stimulation
• Conclusion
Field Background

Yowlumne Field

- Onshore oil field in California (3100 acres)
- Field discovered: 1974
- 1st oil: 1974
- WF unit A and B: 1979, 1982
- Geologic play: Turbidite complex
- Reservoir target: Steven formation
- 82 producers + 32 injectors

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>OOIP</td>
<td>290</td>
<td>MMSTB</td>
</tr>
<tr>
<td>Depth</td>
<td>10000 – 13000</td>
<td>ftTVD</td>
</tr>
<tr>
<td>( \phi )</td>
<td>19</td>
<td>%</td>
</tr>
<tr>
<td>k</td>
<td>50-75</td>
<td>md</td>
</tr>
<tr>
<td>h</td>
<td>150 – 250</td>
<td>ft</td>
</tr>
<tr>
<td>( P_i )</td>
<td>5650</td>
<td>psi</td>
</tr>
<tr>
<td>( P_b )</td>
<td>2740</td>
<td>psi</td>
</tr>
<tr>
<td>( T_r )</td>
<td>240</td>
<td>deg F</td>
</tr>
<tr>
<td>API gravity</td>
<td>34</td>
<td>deg</td>
</tr>
<tr>
<td>Oil viscosity</td>
<td>0.52</td>
<td>cp</td>
</tr>
</tbody>
</table>
Focus on Steven formation only since it carries majority of OOIP (>90 %)
Strategy and Given

**Strategy**
- Optimize oil production and maximize field reserves up to its potential limit
- Minimize cost and maximize NPV of the project
- Select the most suitable well completion to satisfy all requirements
- Identify all formation damages possibility and ways to prevent/solve
- Propose the feasible stimulation options to improve well productivity

**Given**
- An onshore oil field located in an urban area
- Sandstone reservoir in turbidite complex system
- High heterogeneity and reservoir properties variation
- Waterflooding recovery is mature (current RF \approx 26 \%) 
- Staggered line drive + 5-spot pattern
**Well Completion**

### Artificial lift selection

<table>
<thead>
<tr>
<th>Condition</th>
<th>Gas Lift</th>
<th>ESP</th>
<th>PCP</th>
<th>BP</th>
<th>Jet Pump</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production</td>
<td>Moderate</td>
<td>Very High</td>
<td>Moderate</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Depth/Deviation</td>
<td>Very High</td>
<td>High</td>
<td>Poor</td>
<td>Low</td>
<td>Very High</td>
</tr>
<tr>
<td>Scale</td>
<td>High</td>
<td>Poor</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>Sand</td>
<td>Very High</td>
<td>Moderate</td>
<td>High</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>Paraffin</td>
<td>Poor</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Corrosion</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>High</td>
<td>Moderate</td>
</tr>
<tr>
<td>High GOR</td>
<td>Excellent</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Low</td>
<td>Moderate</td>
</tr>
<tr>
<td>Flexibility</td>
<td>Very High</td>
<td>High with VSD</td>
<td>High with VSD</td>
<td>Very High</td>
<td>Very High</td>
</tr>
<tr>
<td>Efficiency</td>
<td>Poor</td>
<td>High</td>
<td>Very High</td>
<td>High</td>
<td>Moderate</td>
</tr>
<tr>
<td>Ability to lower BHP</td>
<td>Poor</td>
<td>High</td>
<td>Moderate</td>
<td>Very High</td>
<td>Moderate</td>
</tr>
</tbody>
</table>

ESP is also suitable for the urban area due to
- Small foot print (less surface requirement)
- Less operation noise
Well Completion

- Slanted hole is preferred
  - Offer high formation exposure
  - Wells can be grouped as a cluster on surface -> suitable for our urban field
- Cased hole completion + selective perforation is used to access only oil sand (not water sand or shale)
- ESP is the most suitable artificial lift
- No sand control requirement – no sand production problem
Well Completion

Y-tool is recommended to be installed with ESP in some wells

- High heterogeneous reservoir --> uneven water breakthrough is anticipated
- Monitor production/injection profile (sand by sand)
- Better reservoir management

Injection well completion → Cased hole + single zone completion is recommended

- Able to monitor water injection profile (ILT)
- Can do conformance control without workover
Formation Damage

- Cased hole completion + ESP installation
  - Filtration of mud, cement and completion fluid will create unavoidable damage near wellbore

- Severe sand production problem is not expected
  - Sonic log shows $\Delta t \approx 80$–$90$ ms ($< 100$ ms) which indicates consolidated sand
  - Sand control should not be installed since it will create more restriction
Formation Damage

- Scale related to water compatibility issue may not severe
  - Produced water has been used as the main water source
  - Sand filter should be used to remove dirt before re-injection
  - Anyway, compatibility test is recommended to be conducted

- Clay analysis shows high Kaolinite and Illite contents
  - Kaolinite can create severe formation plugging if water injection rate is too high.
  - Illite will trap the broken Kaolinite and make things worse
  - Recommend to inject water slowly and nicely
  - Hall’s plot should be used to monitor formation plugging
Factors that limit production potential

- Near wellbore formation damage is created by
  - Mud / cement / completion fluid filtration
  - Clay plugging
- Low productivity sand in the northern part of Yowllumne
  - Deepest part of the field (compaction reduces formation permeability)
  - Distal-fan margin of the turbidite (poor sand quality)

Two stimulation options to minimize those effects and improve well productivity

- Hydraulic Fracturing
- Acidizing
Hydraulic Fracturing

- Reservoir simulation suggests that HF has potential to improve oil recovery
- Slanted well is better than vertical well (higher formation exposure)
- Mini-frac is strongly recommended to conduct prior to main HF to obtain key parameters (fracture gradient, fluid loss coefficient, fracture geometry)
- Separated HF stages is recommended. Since reservoir is high heterogeneous, rock properties in each sub-sand can be significantly different.
- Low productivity formation is the first priority
Acidizing

- Not good with sandstone in the turbidite system
- Considerable Chlorite content in clay is sensitive to acid → may create additional formation damage instead
- Compare to the HF, acidizing is less attractive
Conclusion

• Yowlumne is a mature waterflood field with turbidite complex system located in an urban area
• Cased hole completion with ESP is recommended to optimize production
• Y-tool should be installed to monitor production profile in key wells
• Single zone completion is recommended for water injector
• Main causes of formation damage are fluids filtration and clay plugging
• There are low productivity formations located in the northern part
• Hydraulic fracturing is recommended to bypass near wellbore damage to improve well productivity
• Acidizing is less preferred
Thank You
Back Up
**Suggestion**

- Since waterflood almost reaches its limit,
  - EOR feasibility study is conducted
  - Gas injection is the most attractive method

<table>
<thead>
<tr>
<th>EOR method</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen and flue-gas flooding</td>
<td>Possible</td>
</tr>
<tr>
<td>Hydrocarbon miscible flooding</td>
<td>Very good</td>
</tr>
<tr>
<td>CO₂ miscible flooding</td>
<td>Very good</td>
</tr>
<tr>
<td>Immiscible gas flooding</td>
<td>Very good</td>
</tr>
<tr>
<td>Miscellar/Alkaline flooding</td>
<td>Possible</td>
</tr>
<tr>
<td>Polymer flooding</td>
<td>Unfavourable</td>
</tr>
<tr>
<td>Steam flooding</td>
<td>Unfavourable</td>
</tr>
<tr>
<td>Insitu combussion</td>
<td>Unfavourable</td>
</tr>
</tbody>
</table>

- For producers that will be converted to gas injector, conventional ESP completion is recommended to be replaced by thick-wall tubing with inserted pump
  - Easy to convert to gas injector
  - Maximize completion life (no need workover with new completion)
  - Save cost
- Formation damage created by gas injection requires further study
Field Production History

![Plot of Yowlumne Strip Model History Match](image)

- **Model Oil (STB/D)**
- **Model Gas (MSCF/D)**
- **Model Water (STB/D)**
- **Actual Oil (STB/D)**
- **Actual Gas (MCF/D)**
- **Actual Water (BBL/D)**

Year:
- 1976
- 1978
- 1980
- 1982
- 1984
- 1986
- 1988
- 1990
- 1992
- 1994
- 1996
Fig. 6: Yowlimne field production and injection.
Field Production History

Fig. 7—Yowumna Unit "A" production/injection history.

Fig. 8—Yowumna Unit "B" production history.
Production – O/W/G/I Profiles
Reservoir Pressure History

Yowlumne Strip Model History Match

Average Reservoir Pressure, psig

Year

### PVT Data

**Input Data**

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reservoir Lithology</td>
<td>ss</td>
<td>ls, ss</td>
</tr>
<tr>
<td>Reservoir Depth</td>
<td>12,250.00</td>
<td>feet</td>
</tr>
<tr>
<td>Reservoir Pressure</td>
<td>5,650.00</td>
<td>psia</td>
</tr>
<tr>
<td>Reservoir Temperature</td>
<td>260.00</td>
<td>°F</td>
</tr>
<tr>
<td>Reservoir Porosity</td>
<td>0.19</td>
<td>percent</td>
</tr>
<tr>
<td>Oil Gravity</td>
<td>31.00</td>
<td>°API</td>
</tr>
<tr>
<td>Bubble Point Pressure</td>
<td>2,740.00</td>
<td>psia</td>
</tr>
<tr>
<td>Gas Gravity</td>
<td>0.90</td>
<td>dim</td>
</tr>
<tr>
<td>CO2 Content</td>
<td>0.01</td>
<td>percent</td>
</tr>
<tr>
<td>H2S Content</td>
<td>0.60</td>
<td>percent</td>
</tr>
<tr>
<td>Water Salinity</td>
<td>0.02</td>
<td>weight percent solids</td>
</tr>
</tbody>
</table>

**Reservoir Properties**

<table>
<thead>
<tr>
<th>Property</th>
<th>Calculated Values</th>
<th>Units</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure Gradient</td>
<td>0.461</td>
<td>psi/ft</td>
<td></td>
</tr>
<tr>
<td>Geotheermal Gradient</td>
<td>0.021</td>
<td>°F/ft</td>
<td></td>
</tr>
<tr>
<td>Formation Compressibility</td>
<td>2.828E-06</td>
<td>1/psi</td>
<td>Newman</td>
</tr>
</tbody>
</table>

**Gas Properties**

<table>
<thead>
<tr>
<th>Property</th>
<th>Calculated Values</th>
<th>Units</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molecular Weight</td>
<td>26.073</td>
<td>lb/lb-mol</td>
<td></td>
</tr>
<tr>
<td>Deviation Factor</td>
<td>1.065</td>
<td>dim</td>
<td>Beggs &amp; Brill, Wichert-Aziz</td>
</tr>
<tr>
<td>Compressibility (Ideal Gas)</td>
<td>1.77E-04</td>
<td>1/psi</td>
<td>Ideal Gas Law</td>
</tr>
<tr>
<td>Formation Volume Factor</td>
<td>0.0007</td>
<td>bbl/scf</td>
<td></td>
</tr>
<tr>
<td>Viscosity</td>
<td>0.0339</td>
<td>cp</td>
<td>Lee-Gonzalez-Eakin</td>
</tr>
</tbody>
</table>

**Oil Properties**

<table>
<thead>
<tr>
<th>Property</th>
<th>Calculated Values</th>
<th>Units</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gravity</td>
<td>0.871</td>
<td>dim</td>
<td>Standing</td>
</tr>
<tr>
<td>Solution Gas-Oil Ratio</td>
<td>580.27</td>
<td>scf/stb</td>
<td>Standing</td>
</tr>
<tr>
<td>Solution GOR @ Bubble Point</td>
<td>580.27</td>
<td>scf/stb</td>
<td>Standing</td>
</tr>
<tr>
<td>Compressibility</td>
<td>9.33E-06</td>
<td>1/psi</td>
<td>Vasquez-Beggs &amp; Villena-Lanzi</td>
</tr>
<tr>
<td>Formation Volume Factor</td>
<td>1.378</td>
<td>rbbl/stb</td>
<td>Standing</td>
</tr>
<tr>
<td>Dead Oil Viscosity</td>
<td>2.392</td>
<td>cp</td>
<td>Egbogah</td>
</tr>
<tr>
<td>Live Oil Viscosity</td>
<td>0.621</td>
<td>cp</td>
<td>Beggs-Robinson</td>
</tr>
</tbody>
</table>

**Water Properties**

<table>
<thead>
<tr>
<th>Property</th>
<th>Calculated Values</th>
<th>Units</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solution Gas-Pure Water Ratio</td>
<td>28.4549</td>
<td>scf/stb</td>
<td>McCain</td>
</tr>
<tr>
<td>Solution Gas-Water Ratio</td>
<td>28.4324</td>
<td>scf/stb</td>
<td>McCain</td>
</tr>
<tr>
<td>Compressibility</td>
<td>3.29E-06</td>
<td>1/psi</td>
<td>Yousif</td>
</tr>
<tr>
<td>Formation Volume Factor</td>
<td>1.048</td>
<td>rbbl/stb</td>
<td>McCain</td>
</tr>
<tr>
<td>Viscosity @ Atmospheric P</td>
<td>0.215</td>
<td>cp</td>
<td>McCain</td>
</tr>
<tr>
<td>Viscosity @ Reservoir P</td>
<td>0.285</td>
<td>cp</td>
<td>McCain</td>
</tr>
</tbody>
</table>
Yowlumne Formation Cross Section

West

- Left-stepping Geometries

East

- 85X-5
- 25X-4
- 44X-4
- 63X-4
- 23X-3
- 44X-3
- 45-3
- 64-3RD
- 76X-3
- 16-2RD
- 16-2

D

D'

A sand
B sand
C sand
D sand
E sand

Yowlumne Reservoir

- 285 ft (87 m)
- 2.5 miles (1.5 km)
Producers and Injectors Location
Yowlumne Fan

Diagram showing the Yowlumne Fan with labeled units and sand axes:

- **Unit B lobe**
  - B sand axis
  - C sand axis
  - D sand axis
  - E sand axis

- **Unit A lobe**
  - South Yowlumne lobe

Legend:
- 0 to 1 mile
- 0 to 1 km
- North (N)
Relative Permeability and Capillary Curve
Fractional Flow

- Fractional Flow

- Graphs showing relationships between Sw (water saturation) and various flow parameters (fw, dfw/dSw, WOR, kro, krw)
Well Completion

- Current configuration
Stimulation

Hydraulic Fracturing Process

- Sliding sleeve frac system
- Eliminates the need for wireline system to pump down BHA compared to PNP
- Effectively deployed to long formation depths
- Economical multi-stage fracturing

Frac fluid characteristic

- Cross-linked guar gel with sintered bauxite as proppant
- Gel increases fluid viscosity; improves proppant transport
- Fluid loss reduction
- Average pump rate of 22 BPM

Acidizing

- Not feasible with sandstone in the turbidite system
- Considerable Chlorite content in clay is extremely sensitive to acid → plug