How to get the most out of your Oil Rim Reservoirs? Reservoir management and hydrocarbon recovery enhancement initiatives

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Principal Reservoir Engineer
Outline:

- Oil Rim definition/concept/Challenges
- Guidelines/best practices/key technologies/success factors
- Reservoir and business management and exploitation strategies
- Successful field application and examples
- Closing Remarks
Oil Rim
Opportunity and Headache!

- Limited Thickness
- Overlain by Gas Cap
- Underlain by Aquifer
Forces Balance Mechanism:

- Preservation of Reservoir Energy
- Maximizing the hydrocarbon recovery
Technical Challenges:

• Water/Gas Coning and Break-through
• Spread Out Resources
• Complicated Production Mechanism
• Transition and Invasion Zones
• Oil Smearing
• Low Recovery Factor (<18%)

Business Challenges:

• Different focus for the host company and the operator
• Narrow window of opportunity for “Oil rim” development
• Early gas commitment vs. oil rim IOR development
• Expensive Field Development and marginal economy
Oil Recovery Factor: Main Affecting Parameters

- Oil Thickness
- Permeability
- Aquifer support
- $K_v/K_h$
- Gas Cap Size
- Viscosity and mobility
- $S_{or}, P_c, K_r$

- Well Placement
- Production Strategy
- GIGP
- Reservoir well Contact
- HW vs VW
Oil Recovery Factor: Main Affecting Parameters (Cont.)

- **Oil viscosity effect**

- **Kv/Kh effect**

- **Gas cap size effect**
### Available Screening Tools

#### Traffic Light Guideline

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Category 1</th>
<th>Category 2</th>
<th>Category 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Oil Column size</strong></td>
<td>&lt; 30 ft</td>
<td>30-70 ft</td>
<td>&gt; 70 ft</td>
</tr>
<tr>
<td><strong>Gas cap size</strong></td>
<td>m&gt;7 and/or FGIIP &gt; 1 TSCF</td>
<td>m&gt;2 and/or FGIIP &gt; 200 BSCF</td>
<td>M&lt;=2 and/or FGIIP &lt;= 200 BSCF</td>
</tr>
<tr>
<td><strong>Mobility</strong></td>
<td>Perm &lt; 500 mD Visc &gt; 1cP</td>
<td>Perm 500-1000 mD Visc &gt; 1cP</td>
<td>Perm &gt; 1000 mD Visc &lt; 1cP</td>
</tr>
<tr>
<td><strong>Aquifer Strength</strong></td>
<td>Weak, &lt;25% of total drive</td>
<td>Mid, ~50% of total drive</td>
<td>Strong, &gt;70% of total drive</td>
</tr>
<tr>
<td><strong>Reservoir Geometry/Dip</strong></td>
<td>Complex geometry Large dip uncertainty</td>
<td>Complex geometry Small dip uncertainty</td>
<td>Simple geometry None or small dip uncertainty</td>
</tr>
</tbody>
</table>
Available Screening Tools

Development Strategy

Rim Thickness [ft]

M Factor

Gas

Concurrent Oil & Gas

Oil and then Gas

Source: SPE 128603
Available Screening Tool: Shortcomings

• Successful development in:
  - Thickness < 30 ft
  - $K < 375 \text{ mD}$
• Not in line with the guideline
• 4 to 10 m oil column development

Source: C&C Reservoir and IHS Energy

• Technical Initiatives
• Technology Roles
Oil Rim Development Success Factors

- Robust geological understanding and input rock/fluid data
- Holistic and Integrated development concept
- Adequate and reliable simulation/prediction (Grid, CTZ, HZ well, smart comp., etc.)
- Transition Zone Characterization and modeling
- New well technology applications (long HZ, multi lateral/target, etc.)
- Innovation Technical Initiatives (force balancing efforts, dual smart comp, multi-zone production with FCV, etc.)
- Well/completion design/type/length/offset
- Proactive real time reservoir management & monitoring (PLT, Tracer, PDG, etc.)
- Phasing development to understand the reservoir/well behaviors
Production/Depletion Strategy

Gas Cap Blowdown
- Early Gas prod.
- Oil prod. Ignored!
- Oil smearing concern
- Low oil RF

Sequential Development
- Early oil prod.
- Gas come later
- Commitment concerns
- Different contractual interest
- Higher oil/gas RF

Concurrent Development
- Early oil and gas prod.
- Limited gas prod.
- Up to 10% of the GIIP per annual
- Might suit to both operator and host company interest
- Lower oil RF

Swing Development
- Cyclic oil and gas prod.
- Balance the energy
- Suitable for reservoir with big gas cap
- Lower oil RF

• The FDP, well design and philosophy, RMP is highly dependent on selected strategy
Oil Rim Reservoir and Business Management

- Well type
- Well length, spacing, stand off
- Contact movements
- GOR and production constraint
- Coning, Cusping, Cresting
- IOR/EOR
- Gas cap Blowdown
- Sequential
- Concurrent
- Swing
- Incorporated with IOR/EOR?

- Robust static/dynamic models
- Gas cap size
- Aquifer size and extension
- Driving mechanism contributions
Fluid Sampling, Analysis and PVT

- Usually simplified!
- Surface sample can be misleading
- Both phases need to be sampled
- Recombined with the GIIP/STOIIP ratio
- Reliable fluid model is a must
- Modeling just Oil can be misleading on the RF evaluation
- Oil and Gas need to be modeled together
- Compositional grading and non-equilibrium concerns

(after Amyx, Bass and Whiting, 1960; courtesy of McGraw-Hill)
Transition Zone and Oil Smearing Concerns

- Saturation modeling?
- Can oil rim move upward to the gas producing well?
- How much is the Sor? Soi/Sor relation to be considered.
- Mobile oil and displaced oil zone?
- Dry oil production! Performance better than prediction!

SPE 143983
SPE 145867
Capillary Transition Zone Flow Dynamic

• Dry oil production! Performance better than prediction!
• Sw Modeling:
  • Resistivity index and wettability effects (esp. in carbonates)
  • SHF from resistivity log using water wet derived n exponent can be different from that derived from drainage PC curve
  • This can over estimate the HC saturation above the transition zone
  • Saturation dependent n exponent may need to be used
• Displaced Oil Zone
• Imbibition curves and hysteresis effects
• Pseudo Kr with artificial high immobile Sw may produce HM but can give poor prediction
• How much is the Sor? Soi/Sor relation to be considered.
Sw Determination and Modeling in Carbonates (IPTC 14588)

Rock Type
Permeability
Heterogeneity
Pore size and Geometry
Wettability
Saturation history
Hysteresis

Non-Archie effects
Sw Determination and Modeling in Carbonates (IPTC 14588)
Sw Determination and Modeling in Carbonates (IPTC 14588)
Capillary Transition Zone Flow Dynamic (1)
Capillary Transition Zone Flow Dynamic (2)
Capillary Transition Zone Flow Dynamic (3)

**Rock/fluid/Sor characterization**

- New Model
- Original Model

**Typical Well Water cut %**

**Typical Well Oil Prod total**

HZ well and smart comp modeling

New Model
Original Model

**History**

20% incremental
Reservoir Modeling and Simulation

- Girding scheme
- Horizontal or non-horizontal corner point geometry grids
- Horizontal grids capture the contact movement more accurately (SPE 39548)
- Local grid refinement (LGR)
- Finer layering scheme (SPE 93137)
- Multi Segmented Well (MSW) approach
Modeling of Horizontal wells with smart completion

Conventional modeling
- Hydrostatic only
- No slip and friction along the well
- Uniform mixture density
- Excessive oil production in early stages

Proposed Technique
- Multi segmented well (MSW) model
- Segment topology to honor the well path
- Coupled to the reservoir model
Modeling of Horizontal wells with smart completion (cont.)

**MSW Capability**
- Reliable wellbore pressure gradient and fluid mixture properties
- Proper representation of the well trajectory.
- Ability to model smart completions (ICD, Inflow Control Device, ICV, Inflow Control Valve)
- Coupled to the reservoir simulation equations

![Graph showing Horizontal Well Oil Production Rate](chart)

Correctly model more pressure drop at heel with MSW
Key Technologies/ Methodologies

• Horizontal and Lateral Wells
• Thin Column Drilling
• Inflow Control Well Design
• Smart Completion Design
• Modeling New Technologies
• Real-Time Reservoir Management
• Real Time Reservoir Modeling
• Improved Sweep
Horizontal Well Basis of Design

Basis of Design

Well Spacing
Optimum Fluid Rate
Distance to GOC/WOC
Lateral/perforation length
Smart Completion

Long Well Length

(Madsen and Abtahi- 2005)
**Horizontal Well with Smart Completion**

Smart Completion (ICD, ICV):
- Transmit delta-P along well
- Heel-to-Toe effect reduction
- Higher well PI.
- Better sweep efficiency.

Without ICD     With ICD

Iron Duke Field (SPE 81107)

World wide Installation Forecast!

(OTC-19172)
ICD Minimizes Toe-Heel Effect (OTC-19172)

Screen Standalone

World wide Installation Forecast!

Uniform Drawdown along the well
Improve the well contact with the reservoir-1!

- **Brunei Shell Iron Duke Field (SPE 81107)**
  - One H well with smart completion
  - Five zones in two blocks with different reservoir characteristics

- **StatoilHydro Troll Field (SPE 112616)**
  - Known as gas field!
  - 110 HZ sub sea wells with 53 MLT wells
  - Over 13 km well contact
  - Up to 7 HZ branches in different zones

(Henriksen et al., 2006) (SPE 112616)
Improve the well contact with the reservoir-2!

- Total of 41 wells in 3 phases
- Optimal well off set from contacts
- 250 m average well distance
- EUR increases with well No.
IOR/EOR Considerations

• EOR plan integrated in FDP
• Improve IOR through force balance
  ➢ Minimize coning, cresting and cusping
  ➢ Control fluid contact movement
• Produced Gas Injection
  ➢ GIGP Ratio
• Water Injection
  ➢ Injection at GOC (water fencing scheme)
  ➢ Injection at WOC
• Water Alternative Gas Injection
  ➢ Gravity Assisted Simultaneous WAG
  ➢ Lowering residual HC
• Surfactant augmented water flood
14 m oil column
- Known as non-commercial asset!
- Optimization of well spacing and landing
- 200 m lateral spacing for Well A05 & A10
- 4 m, 6 m and 8 m above WOC
- More oil production and delay WBT
Field A: Horizontal well length optimization and tracer application

- 1.6 km horizontal well with ICD completion
- Toe section contribution
- Tracer application in the toe section
- Toe flow contribution in the early stage
- Smart completion allows longer HZ wells
- PLT is planned post WBT.
Field A: Horizontal well A performance with ICD post WBT

- Well-A with 1.9 km length, 4000 BPD, 5% W-cut, Np of 750 MSTB
- Coil Tubing Unit clean out and PLT
- Low (2.5 KBPD) and high (4.5 KBPD) rate flowing condition tested
- Flow contribution from the entire wellbore
Well-04 with 1.6 km length, 4500 BPD, 70% W-cut, Np of 1.5 MMSTB
Coil Tubing Unit clean out and PLT
Low (2.5 KBPD) and high (4.5 KBPD) rate flowing condition tested
Flow contribution from the entire wellbore
Even with ICD, there are more water from the heel
• Although claimed horizontal by drilling contractor, the static pressure/temp/resistivity shows downward deviation.
• Big ICD pore size (4/32 Inch in this case) create small drawdown and it is a challenge to have uniform drawdown along the well (15 psi vs 18 psi, 17% different).
Although claimed horizontal by drilling contractor, the static pressure/temp/resistivity shows downward deviation.

Smaller ICD pore size (3/30 Inch in this case) create bigger drawdown and it is better for having uniform drawdown along the well (58 psi vs 55 psi, 5% different).
Field A: Improving the hydrocarbon recovery

- Horizontal wells with ICD completion
- MSW approach for well modeling
- 11% RF increase on “No ICD” case.
- This happened through:
  - Draw down management
  - Gas suppression
  - WBT control
- ICD pore size can be further optimized!
- Reservoir heterogeneity along the well
Field A: Journey of recovery factor improvement

- 42 Wells
- Accurate TZ characterization
- 20 Wells
- Proper HZ and smart well modeling
- 16 Wells
- Economical phase 3
- 32 Wells
- Optimizing the number of wells

- Long HZ Well
- 6-8 m offset from OWC
- Accurate TZ characterization
- Project Phasing
- 27 Wells
- Proper HZ and smart well modeling
- Horizontal wells + ICD
- Economical phase 3
- Gas cap gas reinjection
- Optimizing the number of wells
- 4 m offset from OWC
- Idle well re-activation

Recovery factors:
- 16% before Phase 2
- 20% after Phase 2
- 23% after Phase 3
- 32% after Phase 4
- >34% after Phase 5
Field B: Optimized Production Strategy in a Malaysian Carbonate Oil Rim

- Known as gas field!
- Concurrent Oil and Gas development
- Oil and gas production through the same well
- Dual smart completion with ICV
- Development cost reduction

<table>
<thead>
<tr>
<th>Cases</th>
<th>Oil Recovery (MMSTB)</th>
<th>GAS Recovery (BSCF)</th>
<th>Well No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original FDP</td>
<td>41</td>
<td>375.4</td>
<td>7 + 4</td>
</tr>
<tr>
<td>Opt. attempt (1)</td>
<td>38.3</td>
<td>383.1</td>
<td>7</td>
</tr>
</tbody>
</table>

Optimized Well Design

- FDP well design
- GAS CAP
- OIL RIM
- Aquifer
Well Position vs EUR in Field B

- 2 km HZ well
- Gas offtake effect
- Aquifer effect
- ICD vs SSD
Field C: Withdrawal control from different zones

- 10 m oil column
- FCV with PDG application
- Close performance monitoring
- Valve optimization
- PBU survey
Improving the hydrocarbon recovery in Field C

- Horizontal wells with ICD completion
- Multi zone production with Flow Control Valve
- HZ well and smart completion modeling
- 6% RF increase upon "No ICD" case.
- Recommend longer HZ well, PDG, optimum well placement, pilot hole and contact monitoring
- Recommend static/dynamic model revisit

Gain: + 0.244 MMstb

Gain: + 0.214 MMstb

Gain: + 0.082 MMstb
Field D: Improving the hydrocarbon recovery

- **Recovery factor vs GI/GP**

- **Journey of recovery factor improvement**

- Reactivate Idle Wells
- Side Tracks
- Infill Wells

- Selective Water Injection
- Fencing at GOC
- Periphery at WOC

- No Further Action
- 75% Idle Wells

- 34%
- 46%
- >50%
RF Sensitivity to GI/GP in Field D

- GI/GP Management
- Recovery factor vs GI/GP
Field E: Smart HZ Well Application in Small Oil Pocket

- 4 MMSTB STOIIP
- 8 m oil column
- Gas cap size M ratio=1.7
- Vertical well EUR=0.17 MMSTB
- 500 m Smart HZ Well EUR=0.9 MMSTB
- UDC= USD 18/bbl
- Oil column thickness as low as 5 m with HZ well with ICD
Field G: New EOR Scheme

EOR Scope:
- 50 MMscfd Gas Inj.
- 4 Downdip Injectors
- 50 kbwpd Water Inj.
- 5 Updip Injectors
- 22 Reactivations
- 4 Infill Producers

Recovery mechanisms
- Re-pressurizing reservoir
- Sweeping remaining oil towards new wells
- Improved vertical sweep using gravity assistance
- Pushing attic oil back down to producers
- Reduced $S_{or}$ with respect to gas in water swept layers
Field K: Do we need HZ well with ICD?

- Oil column = 6 m
- \( m = 2.0 \)
- \( \Phi_{avg} = 25\% \), \( k_{avg} = 500 \text{ md} \)
- \( P_{ini} = 2100 \text{ psia}, T_{res} = 226 \text{ deg F} \)
- Strong aquifer

![Graph showing well results with and without equalizer.](image)
Case 9: Smart Horizontal Well modeling in a Malaysian Oil Rim

- 7% error over conventional methods
- 16% gain with ICD in well level
- 6% gain with ICD in field level

ICD Design
- Tubing OD 5.5”, ID 4.892”
- ICD port size 3/32”
- ICD interval 11m
Case 5: Withdrawal Mis-Management in Field F

- Gas Cap production
- Oil loss to the gas cap
- Lower RF

Highest Known Water in NL_A3ST2 @ 1695.2 m TVDSS

Original Field OWC @ 1700.6 m TVDSS
~ 2m TV GOC has receded
Original Field GOC @ 1686.6 m TVDSS
Innovative Well Design and Off take Strategy
Closing Remarks:

• Oil rim: good business opportunity with sweet headaches!
• Integration of innovative technical initiatives and new technologies
• Real time/integrated reservoir management, monitoring and surveillances
• Several gas fields and un-commercial assets turned in to attractive oil rim developments
• Success cases on oil column thickness as low as 3 m and STOIIP as low as 3 MMSTB
• Time to change our culture/mindset! Lets follow all the success factors

Oil rim development can be reality now!
Lets move toward breaking the hydrocarbon recovery limit with lower cost!
Thank You!

Question?

-1.5 m
-Can we develop?!

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