Reservoir Pressure Response

8 July 2010
Outline

- Modelling used preliminary slab model
  - Structural model incomplete Wed. evening
  - PIE used to cross-check
- Fixed Parameters:
  - M110 Size (45 mmr
- Sensitivity Parameters:
  - Aquifer: 3.8x, 13.7x, 24x (larger aquifers with some K red' n)
  - Cr: 6, 12, 18 µsips
  - Oil Rate: 35, 50, 60 mbd
  - Skin: 0, 10, 20
  - Xflow 0, ??, ?? rb/d (approximate, controlled with skin)
Depletion

- Aquifer Impact (referenced to 4x Aquifer, 6 μsips, @35 mbd)
  - No Aquifer: -800 psi
  - 13.7x Aquifer: +120 psi
  - 24x Aquifer: +130 psi
- Compressibility
  - 12 μsips: +200 psi
  - 18 μsips: +300 psi
- S.I. BHP Range (M56E, 25 hrs)
  - Near well: 7,900 - 11,030 - 11,120
  - Reservoir: 9,360 - 11,360 - 11,590
  - Recommend: new "most likely". 3.8x aquifer, 12 μsips, 35 mbd

M56E H/C Pressure
Rate = 35 mbd

Colours: aquifer size
4x, 14x, 24x
Shapes: C

Note: Values reflect additional 10 days of depletion
Post Shut-In Behaviour

- Bottomhole pressure changes very rapidly for first 3 hours
  - \( \Delta P/\Delta t > 30,000 \) psi/hr
- Differences
  - Layer crossflow
    - 2 layers vs. many
  - Solution method & timesteps
  - Similar solutions during critical period (5 < t < 100 hrs)
Variation of $\frac{\Delta P}{\Delta t}$ with Parameters: $Q_o$ & $X_{flo}$

$\Delta P/\Delta t$ of $\sim 5 - 10$ psil/hour for rates between 35 & 60 mbpd at 5 hours of shut-in

$\Delta P/\Delta t$ of $\sim 1$ psil/hour for crossflow between 0 & 30 mbpd at 5 hours of shut-in
ΔP/Δt at 5 hours

- Insensitive to:
  - Aquifer (1 psi/hr)
  - Compressibility (1 psi/hr)

- Largest sensitivities:
  - Crossflow
  - Average production rate
  - Sensitivity to Qₘ > Xfₘ
Input Data

- Data provided by GolMx Reservoir Team
- Rock Properties
  - Developed from MC252 logs
  - Permeability
    - 275 mD in main M56E sand
    - 397 mD in M56A gas/oil sand (only 2.5)
    - 86 – 110 mD in other oil sands
  - Compressibility:
    - Cr: 6 x 10^6 psia^-1
    - Cw: 3 x 10^6 psia^-1
    - Cf: ~13 x 10^6 psia^-1
- Fluid properties generated by EoS; volatile, near critical fluid
- Tubing performance matched to GAP / Prosper work of T. Liao, A. Chitale & M Goldemir
Macondo RF – Aquifer Size

Oil Accumulation
110 mmstb = 258 mmrb

<table>
<thead>
<tr>
<th>Net Sand Thickness, ft.</th>
<th>Porosity, %</th>
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<tbody>
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<td>1.5x</td>
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<td>17</td>
<td>2.0x</td>
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Aquifer = 992 mmrb

Largest Aquifer Size – used as base case (will minimise depletion)
Depletion Response @wellbore

- PIE gives similar results to VIP
  - Constant compressibility (too low)
  - Single phase
- $P_{mf}$ drops ~6 psi/day (for 35mbd case)
- Lack of observed depletion could be due to fixed seafloor pressure and large critical

Possible impact of seafloor pressure

- Sea = 2370 psi
- BHP = 1800 psi
- Max $Sp = 1.36$
Conclusions

- Actual reservoir depletion dependent on:
  - Flowrate
  - Oil column size
  - Aquifer
- Limited depletion observed in wellhead could be controlled by non-reservoir mechanisms
  - Large orifice
  - Flowpath / choke between BOP & reservoir
  - Broken gauge
  - Crossflow
- Largest uncertainties: flowrate and pressure drop

BP-HZN-2179MDL07033650
BPD568-013655
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DRAFT
Match to "Tubing Performance"

- Flowpath is a major (principle?) source of THP uncertainty
- Various cases considered:
  - Annular flow
  - Casing flow
  - Annular + casing flow
- VIP wellbore modelling capability limited in comparison with Prosper / Gap
  - Matched lift with simple tubing string
  - Equivalent diameter & roughness
Influences on Observable Shut-In Pressure

At Shut-In

High Wellhead Pressure
- Limited crossflow
- Well integrity above 18" shoe
  - small leak into small zone
- Large aquifer
- Lower production (higher skin)

Low Wellhead Pressure
- Integrity failure (crossflow into M110)
- Smaller aquifer
- Higher production (& lower skin)

After Shut-In

Rising THP
- Fluid Segregation
  - Only if $P_{bg} < 6,550$psi
  - Increase would begin at low rates or
    at flow cessation
- Reservoir Response (radius of
  investigation)
- Aquifer size will influence $P_{sat}$
- Cessation of crossflow (pressure
  equilibration)

Falling THP
- Wellbore temperature equilibration
  (cooling)
- Large leak with limited inflow
MBal Results for Various Aquifers

![Graph showing water levels over time for various aquifers.](image-url)
Future Work: Add Structure
Key Conclusions wrt SiWHP

- Impact of crossflow:
  - Reservoir fluid fills the M110, charging it above fracture capacity
  - Possible broach to surface
- M110 sand is small (5' thick), in one scenario could fill to fracture pressure in 10 days (resvr flow > 32mbd).

Can we detect this scenario?
- Leak off will not be detectable (constant charge from M56)
- Crossflow at 18" shoe would be detectable if "large enough"
  - Max Q, through 6 disks: 6000 bpd
- Would manifest itself as a lower than "anticipated" SI BOP pressure
- Uncertainty in SI BOP pressure is driven by aquifer & rate
Model Approach & Purpose

- Model constructed to address impact of crossflow of M57B & M56A gas sands during "top kill"
  - Response of observed pressures
  - GOR variation with time
- Requested to investigate whether depletion was consistent with known pressures below BOP
- Requested to avoid making any conclusions regarding likely rates
  - Role of flowrate investigation team

Approach
- Simple: tight timing, multiple unknowns
- Single layer per reservoir (M57B to M56F, with intervening shales)
- 10 x 12 x 17; no structure
Outline

- Modelling used preliminary slab model
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  - Reservoir: 9,360 - 11,360 – 11,590

- Recommend: new “most likely”: 3.8x aquifer, 12 μsips, 35 mbd

M56E H/C Pressure

Rate = 35 mbd

Note: values reflect additional 15 days of depletion
Post Shut-In Behaviour

- Bottomhole pressure changes very rapidly for first 3 hours
  - $\Delta P/\Delta t > 30,000$ psi/hr
- Differences
  - Layer crossflow
    - 2 layers v. many
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$\Delta P/\Delta t$ of $\sim 5 - 10$ psi/hour for rates between 35 & 60 mbd at 5 hours of shut-in

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\( \Delta P/\Delta t \) at 5 hours

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Macondo RF —
Aquifer Size

Oil Accumulation
110 mmstb = 258 mmrb

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![Graph showing pressure vs. time for Macondo M1 Shut-In experiment with skin values of 10, 20, and 30.]

![Diagram showing possible impact of seafloor orifice with water column at 2270 psi + $\Delta P$, BOP $\Delta P=10$ psi, and maximum $\Delta P=1,340$.]

Depth, ft/Vdss

Flowing BH Pressure
Conclusions

- Actual reservoir depletion dependent on:
  - Flowrate
  - Oil column size
  - Aquifer
- Limited depletion observed in wellhead could be controlled by non-reservoir mechanisms
  - Large orifice
  - Flowpath / choke between BOP & reservoir
  - Broken gauge
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\[ 2270 \text{ psi} \]
\[ \text{ambient} \]
Difference between Aquifer & H/C Pressure
Match to "Tubing Performance"

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- Various cases considered:
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- Reservoir Response (radius of investigation)
  - Aquifer size will influence $P_{final}$
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