Modelling Gas Well Liquid (Un)Loading

Kees Veeken (NAM, Assen)
Murat Kerem (Shell, Rijswijk)
Objectives of Modelling

- **Liquid loading**
  - Improve capacity forecast to maximise nomination
  - Determine proven and expectation reserves
  - Predict end of field life i.e. abandonment date
  - Predict date that deliquification should be installed

- **Liquid unloading (a.k.a. deliquification)**
  - Determine SFR and reserves at stake
  - Generate incremental forecast to justify investment
  - Select best (sequence of) deliquification measures
  - Optimise deliquification techniques and implementation
Contents

• Objectives
• Well & reservoir model
• Abandonment pressure & ultimate recovery
• Production forecast for deliquification
• Minimum gas rate & metastable production
• Gas well unloading
• Future modelling
Well Model

- Cullender-Smith
  
  \[
  FBHP = FTHP + HH + FF: \\
  FBHP^2 = B \cdot FTHP^2 + C \cdot Q^2
  \]

- Forcheimer
  
  \[
  \text{Pres} = FBHP + DD: \\
  P_{res}^2 - FBHP^2 = A \cdot Q + F \cdot Q^2
  \]

- Turner
  
  \[
  Q_{min} = TC \cdot FTHP^{0.5} \cdot \text{ID}^2 / [(FTHT+273) \cdot Z]
  \]

- Abandonment
  
  \[
  Q = Q_{min}: \\
  P_{ab}^2 = B \cdot FTHP^2 + A \cdot Q_{min} + (C+F) \cdot Q_{min}^2
  \]
Abandonment Pressure & Reserves

**UR** = GIIP \( \times \frac{(P_i - P_{ab})}{P_i} \)

- **UR** = Unrecoverable Reserve
- **GIIP** = Geologic Initial InPlace Gas
- **P_i** = Initial In-situ Pressure
- **P_{ab}** = Abandonment Pressure
- **P_{res}** = Residual Pressure
- **G_p** = Gas constant

[Diagram showing the relationship between abandonment pressure and reserves.]
Compression benefit for all A
Velocity string benefit increases with A
Stimulation increases reserves.
Foam lift benefit increases with A.
Prolific Gas Well (Low A)

GIIP = $10^9$ m$^3$, $A = 4$ bar$^2/(10^3$ m$^3$/d), 5" tubing

- **Base Case**: 77%
- **Compression**: 22%
- **Foamer**: 1%
- **Gas Lift**: 1%

Gremlin Gas Well (Low A)

GIIP = $10^9$ m$^3$, $A = 4$ bar$^2/(10^3$ m$^3$/d), 5" tubing

- **Base Case**: 77%
- **Compression**: 22%
- **Foamer**: 1%
- **Gas Lift**: 1%

**Graph:**
- **Y-axis**: Gas Rate ($10^3$ m$^3$/d)
- **X-axis**: Time (yrs)

**Legend:**
- Base Case
- Compression
- Foamer
- Gas Lift

**Units:**
- Gas Rate: $10^3$ m$^3$/d
- Time: yrs
- Gas Volume: $10^6$ m$^3$
GIIP = $10^9$ m$^3$, $A = 4$ bar$^2/$(10$^3$ m$^3$/d), 5” tubing

Prolific Gas Well (Low A)

Compression/eductor most useful
Reduced scope for other measures
Tight Gas Well (High A)

**GIIP = 10^6 m^3, A = 400 bar^2/(10^3 m^3/d), 5" tubing**

- **Base Case**
- **Compression**
- **Foamer**
- **Gas Lift**

<table>
<thead>
<tr>
<th>Time (yrs)</th>
<th>Gas Rate (10^3 m^3/d)</th>
<th>Gas Volume (10^6 m^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>400</td>
<td>250</td>
</tr>
<tr>
<td>4</td>
<td>37%</td>
<td>32%</td>
</tr>
<tr>
<td>8</td>
<td>21%</td>
<td>21%</td>
</tr>
<tr>
<td>12</td>
<td>10%</td>
<td>10%</td>
</tr>
<tr>
<td>16</td>
<td>10%</td>
<td>10%</td>
</tr>
<tr>
<td>20</td>
<td>10%</td>
<td>10%</td>
</tr>
</tbody>
</table>
Tight Gas Well (High A)

GIIP = $10^6 \text{ m}^3$, $A = 400 \text{ bar}^2/(10^3 \text{ m}^3/\text{d})$, 5" tubing

Deliquification critical for recovery
Scope for wide range of measures
Sharing the same cake
Selection is key

Base Case: 37%
Compression: 32%
Foamer: 21%
Gas Lift: 10%
Tight Gas – Outflow Challenge

Outflow as challenging as inflow!

Gas well deliquification essential to maximise recovery for tight gas wells

2-7/8” tubing
THP 5 bar
H 100m, 1x
RF=0% if K < 10 μD

RF (%)

0%

10%

20%

30%

40%

50%

60%

70%

80%

90%

100%

KH (mD.m)

0.1

1

10

100

1000

Minimum Rate Actual & Turner

![Bar chart showing the number of wells based on the actual minimum rate compared to the Turner criterion. The x-axis represents the actual minimum rate (in units) and the y-axis represents the number of wells. The bars show the following categories: <1.0, 1.0-1.5, 1.5-2.0, 2.0-2.5, >2.5. The chart indicates a significant number of wells in the 1.0-1.5 category.]
Modified Turner

Well more sensitive to pressure fluctuations at low pressure

\[ y = 3.4441x^{-0.1717} \]

\[ R^2 = 0.2085 \]
Turner Literature Data

- **Unloaded**
- **Loaded**
- **Questionable**
- **Success**
- **Failure**

- **Actual Gas Rate (Mscf/d)**
- **Calculated Loading Rate (Mscf/d)**
Dependency on A in Simulator

Q_{min} increases as A decreases

Well more sensitive to pressure fluctuations at low pressure

Prolific

Poor
Model Limitations

- Underestimates hydrostatic head
  - Calculated abandonment pressure too low
  - Uplift when injecting foam just above critical rate (?)
- No recharging due to tight or slow gas
  - Connected volume increases with time
  - Intermittent production
- Monobore only i.e. no wet foot across larger liner
  - Extra back pressure
- No metastable flow
Metastable Gas Production

Gas bubbles through liquid column (SPE 95282)
Stable rate 40,000 m³/d
Metastable rate 12,000 m³/d

Gas Rate
THP
BHP
Metastable Gas Production

Offshore wellhead temperature provides indication of liquid loading & metastable production
Unloading Gas Well

• Gas well unloads far below Turner criterion
• Initial unloading via piston like displacement
• Critical velocity of Taylor gas bubble 10x lower than Turner critical velocity

• Piston model
• OLGA multiphase dynamic flow simulator
Unloading Well with 7” Tubing

$Q_{min,\text{water}} \approx 4\times 10^5 \text{ m}^3/\text{d}$, $Q_{min,\text{condensate}} \approx 2\times 10^5 \text{ m}^3/\text{d}$
Volume Fraction @ 240 min (OLGA)

Q_{gas} \sim 4E4 \text{ m}^3/\text{d}
Volume Fraction @ 480 min (OLGA)

**Q_{gas} \sim 4E5 \, m^3/d**

**Along Hole Distance from Toe (m)**

**Fraction (\cdot)**
Future Modelling

• Liquid loading
  – Update & upgrade modified Turner
  – Resolve abandonment pressure discrepancy
  – Support multiphase dynamic modelling of liquid loading

• Liquid unloading (a.k.a. deliquification)
  – Model interaction between reservoir and well in liquid loading domain to produce better deliquification forecasts & to optimise deliquification techniques
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