The Use of Stability Maps in the Design and Operation of Gas-Lift Wells

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Outline

- Introduction
- Stability Maps for Continuous Flow Gas-Lift Wells
- Comparison of Different Gas-Lift Stability Criteria
- Stability Map Applications
  - Effect of Orifice Size
  - Effect of Tubing Diameter
  - Effect of Injection Depth
  - Effect of Inflow Performance
  - Selection of Stabilization Method
- Conclusions
Heading in a Gas-Lift Well
Problems caused by flow oscillations in gas lifted wells

- Operational problems
  - difficulties with operation of low pressure separator
  - compressor shutdown
- Low efficiency
- Problems with production control
- Monitoring (more difficult to measure production rates)
Gas-Lift Performance Curves

- Production (Mb/d) vs. Gas Injection (MMscf/d)
- Wellhead Pressure (kg/cm²)
Factors Affecting Gas-Lift Stability

1. Fluid properties (crude oil and injected gas)
2. Inflow performance
3. Reservoir pressure
4. Tubing diameter
5. Casing diameter
6. Orifice valve size
7. Injection depth
8. Injection gas rate
9. Wellhead pressure
Existing Techniques and Recommendations

1. Sizing of the injection port (pressure differential of 100-200 psi) ⇒ increased gas compression costs/pipe wall thickness
2. Increasing the injection gas rate ⇒ inefficient operation
3. Choking at the surface (increasing the wellhead pressure) ⇒ uneconomical production
Existing Methods to Analyze Flow Stability in Gas-Lift Wells

- Sensitivity analysis based on gas-lift stability criteria (linear stability analysis)
- Transient models (non-linear stability analysis)
- Both methods - *time-consuming and tedious procedures*
Gas-Lift Application in Offshore Oil Production

- Large-scale oil production
- High percentage of H$_2$S
- Gas processing-onshore
- Long pipelines to transport lift gas
- Pressure variations in the gas allocation network
Boiling Water Reactor (BWR)
Typical BWR Stability Map

\[ N_{\text{sub}} = \frac{(P_f - P_g)(h_f - h_m)}{\rho_g h_{fg}} \]

\[ N_{\text{pch}} = \frac{\bar{q}'' P_H L_H (\rho_f - \rho_g)}{G A_{x-s} h_{fg} \rho_g} \]
Continuous Flow Gas-Lift Well

1 Reservoir
2 Packer
3 Tubing
4 Operating valve
5 Casing
6 Gas allocation network
7 Surface injection choke
8 Wellhead
9 Choke
10 Flowline
GME Computer Program (Stability Map Generator)

Specify system operating conditions

Predict steady-state flow parameters

Select gas-lift stability criteria

Gas-lift well stability map
Gas-Lift Stability Map

Stability Boundary
- Fairuzov and Guerrero, 2004

Operability Boundaries
- Lower limit
- Upper limit

Wellhead Pressure (kg/cm²)

Gas Injection (MMscf/d)
## Well Data

<table>
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<tr>
<th></th>
<th>Value</th>
<th>Unit</th>
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<tr>
<td>Reservoir pressure</td>
<td>1543.31</td>
<td>psig</td>
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<tr>
<td>Reservoir temperature</td>
<td>216.9</td>
<td>°F</td>
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<tr>
<td>Water cut</td>
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<td>percent</td>
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<td>Liquid rate</td>
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<td>STB/day</td>
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<td>Flowing bottomhole pressure</td>
<td>1363.5</td>
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<td>Oil gravity</td>
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<td>API</td>
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<td>Gas gravity</td>
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<td>sp. gravity</td>
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<td>Gas lift gravity</td>
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<td>Solution GOR</td>
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<td>Bubble pressure</td>
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<td>psig</td>
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</table>
Stability Map for Gas-Lift Well with Square-Edged Orifice Valve

- **Operability Boundaries**
  - Lower limit
  - Upper limit

- **Stability Boundary**
- **Optimal Rate**

**Wellhead Pressure (kg/cm²)** vs. **Gas Injection Rate (MMscf/d)**

- **Non-Operational**
- **Stable**
- **Unstable**
Field Data

- Bottomhole pressure
- Wellhead pressure

- 5.5 MMscfd (Choke size: 2.5"")
Comparison of Gas-Lift Stability Criteria

- Stability Boundaries:
  - Asheim, 1988
  - Alhanati et al., 1993
  - Fairuzov and Guerrero, 2004

- Operability Boundary:
  - Lower limit

- Field Data:
  - Green square: Stable
  - Red triangle: Unstable

Wellhead Pressure (kg/cm²) vs. Gas Injection (MMscf/d)
Effect of Orifice Size

Stability Boundaries
- Orifice size
  - 1.00 in.
  - 0.75 in.
  - 0.50 in.

Operability Boundaries
- Lower limit
  - All cases
- Upper limit
  - 0.50 in.
Effect of Tubing Diameter
(d_c = 11 7/8 in.)

Wellhead Pressure (kg/cm²)

Gas Injection (MMscf/d)

Stability Boundaries
Tubing diameter
- 5 1/2 in.
- 7 5/8 in.
- 9 5/8 in.

Operability Boundary
Lower limit
- 7 5/8 in. and 9 5/8 in.
Effect of Injection Depth

Stability Boundaries
Injection depth
- 6830 ft.
- 6174 ft.
- 5518 ft.

Operability Boundary
Lower limit
- All cases

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Effect of Inflow Performance
\( q_o = 7632 \text{ bpd} \)

<table>
<thead>
<tr>
<th>Wellhead Pressure (kg/cm²)</th>
<th>Stability Boundaries</th>
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<tr>
<td>8.4</td>
<td>Lower limit</td>
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<td>12.7</td>
<td>Operability Boundary</td>
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**Operability Boundary**
- Lower limit

**Stability Boundaries**
- Drawdown
  - 12.7 kg/cm²
  - 8.4 kg/cm²
  - 4.2 kg/cm²
Selection of Stabilization Method

Stability Boundaries
- Design conditions
- Decreased injection depth
- Well stimulation
- Reduced choke size

Lower limit
- All cases

Upper limit
- Only for reduced choke size

Design operating condition
- Unstable
Oil Production Rate

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Selection of Stabilization Method

Stability Boundaries:
- Design conditions
- Decreased injection depth
- Well stimulation
- Reduced choke size

Design operating condition:
- Only for reduced choke size
- Unstable

Wellhead Pressure (kg/cm²) vs. Gas Injection (MMscf/d)

- Non-Operational
- Stable
- Unstable

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Conclusions

✓ Stability maps can be used to compare different gas-lift stability criteria.

✓ Existing stability criteria may significantly underestimate the instability threshold for gas-lift wells producing from saturated reservoirs.

✓ New criteria predict more accurately the instability boundary
Conclusions (cont.)

✓ Gas-lift design:
  the effect of gas-lift design parameters and operating conditions on the system stability

✓ Operation:
  what actions should be taken to bring the system into a stable operating state with a minimum increase in operational expenditures

✓ Gas-lift optimization

✓ Training and education