Critical Gas Velocity Maps to Predict Liquid Loading in Gas Wells

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Outline

Introduction

Objective

Applied Methodology

- Considered Operating Conditions
- Dimensionless Number Definition
- Map Example
- Interface

Map Applicability – Case studies

- Case 1: Production Decline Effect
- Case 2: All Wells Visualization
INTRODUCTION
Liquid Loading

When the flowrate of gas wells lowers, liquids get accumulated at bottom-hole causing liquid buildup

• Normally occurs once the well matures
• Lowers production and can eventually kill a well

Current ways to predict critical gas velocity

• Liquid Droplet Model – considers $ID, \beta, \rho_L, \rho_g, \sigma$
• Film Reversal Model – considers $ID, \beta, \rho_L, \rho_g, \sigma, \mu_L, \mu_g, Q_L$
OBJECTIVE
Objective

Develop simple critical gas velocity prediction custom map(s) using Film Reversal Model (Brito 2015)

Map(s) comprises of:

• Critical gas velocity maps that can be used in the field at different pressure conditions and diameters

• Modify the maps to determine
  • when the well become loaded
  • which wells in the field are loaded at a given time

Create an interface for the users to make computations visual and simple
Data was obtained for 30 horizontal gas wells

Following well properties:

• Fluid Properties (Constant)
  – Gas specific gravity ($SG$): 0.57
  – Oil density ($\rho_o$): 45 lb/ft$^3$
  – Water density at SC ($\rho_{w,sc}$): 68 lb/ft$^3$
  – Water cut ($WC$): 100%

• Completion
  – Inner diameter ($ID$): 1.995 in, 4.778 in
  – Deviation angle ($\beta$): 0 - 90 deg
  – Single perforation
Field Data

• Correlations
  - Pseudo properties – Sutton (2005) Condensate
  - Z-Factor – Dranchuk-Abu Kassem
  - Gas viscosity – Lee et al
  - Water-gas interfacial tension – Firoozabadi and Ramey
  - Pressure drop gradient – Beggs and Brill

• Operating Conditions
  - Pressure ($p$): 260 - 1900 psi
  - Liquid flowrate ($Q_{l,sc}$): 0.9 – 23 bpd
  - Gas flowrate ($Q_{g,sc}$)
  - Temperature ($T$)
Film reversal model (Brito 2015)

This software provided the following output data:

- In-situ liquid velocity \(v_{sL}\)
- In-situ liquid density \(\rho_L\)
- In-situ liquid viscosity \(\mu_L\)
- In-situ Interfacial Tension \(\sigma\)
- In-situ gas velocity \(v_{sG}\)
- Critical gas velocity \(v_{sG,c}\)
- Critical gas flowrate \(Q_{g,c}\)
It is defined as,

\[ X = \frac{Re^2 Fr}{We} = \frac{\left[ \rho_L \left( \frac{Q_L}{A} \right)^2 ID^2 \right]^2}{\sqrt{gID}} \left[ \frac{\left( \frac{Q_L}{A} \right)}{\rho_L \left( \frac{Q_L}{A} \right)^2 ID} \right] \frac{\rho_L \left( \frac{Q_L}{A} \right)^2 ID}{\sigma} \]

Simplifying it further,

\[ X = 7.48 \cdot 10^{-7} \frac{\rho_L Q_L \sigma}{\mu_L^2 ID^{1.5}} \sin \beta \]

Where,

- \( \rho_L \) – Liquid density (kg/m³)
- \( Q_L \) – Liquid flowrate (STB/D)
- \( \sigma \) – Interfacial tension (N/m)
- \( \mu_L \) – Liquid viscosity (Pa.)
- \( ID \) – Inner diameter (m)
- \( \beta \) – Inclination angle (radians)
- \( Re \) – Reynolds’ number (-)
- \( Fr \) – Froude number (-)
- \( We \) - Weber Number (-)
Critical Gas Velocity Map Example

Liquid Flowrate

Dimensionless Variable, $X$ (-)

$p = 300$ psi
$ID = 2.00$ in
Critical Gas Velocity Map Example

- Liquid Flowrate
  - \( Q_L = 0.9 \text{ bpd} \)

- Critical Gas Velocity, \( v_{c,g} \)

- Dimensionless Variable, \( X \)

- Angle, \( \beta \)
  - \( \beta \leq 15^\circ \)
  - \( \beta > 15^\circ \)

- Pressure, \( p \) = 300 psi
- ID = 2.00 in
Critical Gas Velocity Map Example

![Critical Gas Velocity Map Example](image-url)
Critical Gas Velocity Map Example

[Graph showing critical gas velocity map with different liquid flowrates (QL) and a dimensionless variable X. The graph includes lines for QL = 0.9 bpd, QL = 1.0 bpd, QL = 1.4 bpd, QL = 1.5 bpd, QL = 1.8 bpd, QL = 3.5 bpd, QL = 6.5 bpd, QL = 8.1 bpd, QL = 10.0 bpd, and QL = 23.0 bpd. The pressure at the boundary is p = 300 psi, and the ID is 2.00 in.]
Before you enter the map ...

Following values are required to obtain the critical gas velocity:

- Pressure \((p)\)
- Diameter \((ID)\)
- Inclination angle \((\beta)\)
- Dimensionless number \((X)\)
- In-situ gas velocity \((V_{sg})\)
- Liquid flowrate \((Q_L)\)
Actual Gas Velocity vs. X

![Graph showing Actual Gas Velocity vs. X](image)

- Liquid Flowrate
  - $QL = 0.9\, bpd$
  - $QL = 1.0\, bpd$
  - $QL = 1.4\, bpd$
  - $QL = 1.5\, bpd$
  - $QL = 1.8\, bpd$
  - $QL = 3.5\, bpd$
  - $QL = 6.5\, bpd$
  - $QL = 8.1\, bpd$
  - $QL = 10.0\, bpd$
  - $QL = 23.0\, bpd$
  - $Actual$

$X$ value

$V_{sg}$ value

$p = 300\, psi$

$ID = 2.00\, in$
Critical Gas Velocity vs. X

- Liquid Flowrate
  - $QL = 0.9$ bpd
  - $QL = 1.0$ bpd
  - $QL = 1.4$ bpd
  - $QL = 1.5$ bpd
  - $QL = 1.8$ bpd
  - $QL = 3.5$ bpd
  - $QL = 6.5$ bpd
  - $QL = 8.1$ bpd
  - $QL = 10.0$ bpd
  - $QL = 23.0$ bpd

- Dimensionless Variable, $X$ (-)

- Critical Gas Velocity, $V_{gc}$ value
- $Q_{c}$ value
- $X$ value

- $p = 300$ psi
- $ID = 2.00$ in
Making sense of the maps …

If the gas velocity is greater than the critical velocity, the well is **unloaded**

But if the gas velocity is less than the critical velocity, the well is **loaded**!
High and Low Pressure Maps

Low Pressure ($p = 400$ psi)

High Pressure ($p = 1800$ psi)
Interface (Map Available)

### Table 1: Gas Properties

| Specific Gravity (SG) | 0.57 | - |

### Table 2: Liquid Properties

| Oil Density | 45 lbm/cu-ft |
| Water Density at SC | 68.5 lbm/cu-ft |
| Water Cut at SC | 1 fraction |
| Water Salinity | 8.5 %wt |

### Table 3: Operating Conditions

| Lower Bound of Pressure | 300 Psig |
| Pressure | 300 Psig |
| Upper Bound of Pressure | 300 Psig |
| Gas Flow Rate at SC (Qgsc) | 500 MSCFD |
| Total Liquid Mixture Flow Rate at SC (QLsc) | 0.9 STBD |
| Temperature | 120 °F |

### Table 4: Casing and Tubing Specifications

| Tubing (1) or Casing (2) | 1 - |
| Tubing ID | 1.995 in. |
| Casing ID | 4.778 in. |
| Pipe Roughness | 0.001 in. |
| Deviation Angle | 10 ° |

### Table 5: Calculated Values for Actual Pressure

| \( v_{SL} \) | 0.00082 m/s |
| \( \rho_L \) | 1097.3 kg/m³ |
| \( \mu_L \) | 0.0010145 Pa.s |
| \( \sigma \) | 0.1357 N/m |
| \( v_{Sg} \) | 14.134 ft/s |

### Table 6: Output

<table>
<thead>
<tr>
<th>Pressure</th>
<th>X</th>
<th>( v_{sg} ) (ft/s)</th>
<th>( v_{sgc} ) (ft/s)</th>
<th>( Q_{gc} ) (Mscfd)</th>
<th>Loading Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>1495.36</td>
<td>14.134</td>
<td>12</td>
<td>2.44</td>
<td>UNLOADED</td>
</tr>
<tr>
<td>300</td>
<td>1495.36</td>
<td>14.134</td>
<td>12</td>
<td>2.44</td>
<td></td>
</tr>
<tr>
<td>300</td>
<td>1495.36</td>
<td>14.134</td>
<td>12</td>
<td>2.44</td>
<td></td>
</tr>
</tbody>
</table>
### Table 1: Gas Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gravity (SG)</td>
<td>0.57</td>
</tr>
</tbody>
</table>

### Table 2: Liquid Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil Density</td>
<td>45, lbf/cu-ft</td>
</tr>
<tr>
<td>Water Density at SC</td>
<td>68.5, lbf/cu-ft</td>
</tr>
<tr>
<td>Water Cut at SC</td>
<td>1, fraction</td>
</tr>
<tr>
<td>Water Salinity</td>
<td>8.5, %wt</td>
</tr>
</tbody>
</table>

### Table 3: Operating Conditions

<table>
<thead>
<tr>
<th>Condition</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Bound of Pressure</td>
<td>300 Psig</td>
</tr>
<tr>
<td>Upper Bound of Pressure</td>
<td>400 Psig</td>
</tr>
<tr>
<td>Gas Flow Rate at SC (Qgsc)</td>
<td>500 MSCFD</td>
</tr>
<tr>
<td>Total Liquid Mixture Flow Rate at SC (QLsc)</td>
<td>0.9 STBD</td>
</tr>
<tr>
<td>Temperature</td>
<td>120 °F</td>
</tr>
</tbody>
</table>

### Table 4: Casing and Tubing Specifications

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tubing (1) or Casing (2)</td>
<td>1</td>
</tr>
<tr>
<td>Tubing ID</td>
<td>1.995, in.</td>
</tr>
<tr>
<td>Casing ID</td>
<td>4.778, in.</td>
</tr>
<tr>
<td>Pipe Roughness</td>
<td>0.001, in.</td>
</tr>
<tr>
<td>Deviation Angle</td>
<td>10, °</td>
</tr>
</tbody>
</table>

### Table 5: Calculated Values for Actual Pressure

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(v_{SL})</td>
<td>0.00082, m/s</td>
</tr>
<tr>
<td>(\rho_L)</td>
<td>1097.3, kg/m³</td>
</tr>
<tr>
<td>(\mu_L)</td>
<td>0.0010145, Pa.s</td>
</tr>
<tr>
<td>(\sigma)</td>
<td>0.1357, N/m</td>
</tr>
<tr>
<td>(v_{SG})</td>
<td>12.055, ft/s</td>
</tr>
</tbody>
</table>

### Table 6: Output

<table>
<thead>
<tr>
<th>Pressure</th>
<th>(X)</th>
<th>(v_{SG}) (ft/s)</th>
<th>(v_{SGC}) (ft/s)</th>
<th>(Q_{GC}) (MSCFD)</th>
<th>Loading Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>1495.36</td>
<td>14.134</td>
<td>11.40</td>
<td>2.31</td>
<td></td>
</tr>
<tr>
<td>350</td>
<td>1482.98</td>
<td>12.055</td>
<td>10.40</td>
<td>2.48</td>
<td>UNLOADED</td>
</tr>
<tr>
<td>400</td>
<td>1470.61</td>
<td>10.496</td>
<td>9.40</td>
<td>2.57</td>
<td></td>
</tr>
</tbody>
</table>
MAP APPLICABILITY
Case 1: Production Decline Effect

Use expected production decline to determine at what point in time the well condition changes from unloaded to loaded.
Example

For this example, the following parameters are considered:

• Well no. 7
• Time step = 60 days
• POI = Wellhead
• Flowrate = 3.5 BPD
• Pressure = 300 psi
• Diameter = 1.995 in
• Inclination Angle > 15°
Full Map
Map – 3.5 BPD

Liquid Flowrate

$QL = 3.5\ BPD$

$\text{p} = 300\ psi$

$\text{ID} = 2.00\ in$

Critical Gas Velocity, $v_{gc}$ (ft/s)

Dimensionless Variable, $X$ (-)

1,000 10,000 100,000

0 5 10 15 20 25 30
After 60 days …

![Graph showing liquid flowrate and critical gas velocity](image)

- Liquid Flowrate
- $Q_L = 3.5 \text{ BPD}$
- Unloaded
- $P = 300 \text{ psi}$
- $ID = 2.00 \text{ in}$
After 120 days …

![Graph showing liquid flowrate over time with specific parameters and conditions.]
After 600 days ... just above the line
After 660 days ...loaded!!

![Graph showing liquid flowrate and critical gas velocity](graph_image)

- Liquid Flowrate
- QL = 3.5 BPD
- Unloaded
- Loaded

**Graph Details:**
- p = 300 psi
- ID = 2.00 in
At the end of well’s life
Case 2: Field Wells Visualization

Based on production data of each well, know which wells are loaded and which are unloaded at a given point in time
In the following example, the following parameters are considered:

- 20 Wells
- Fixed time considered – at 60th day
- POI = 4000 ft
- Flowrate = 1.0 – 23.0 BPD
- Pressure = 900 psi
- Diameter = 1.995 in
- Inclination Angle > 15°
Case 2
A closer look …
Take Away

Both of these cases are very applicable in the field

Avoid losing excess production

Help plan production strategies efficiently and make economical decisions
CONCLUSION
Conclusion

The maps created are based on some constant parameters and correlations – only accurate if all of them are true – if not, additional changes have to be made.

These maps provide an easy estimate of critical gas velocity – useful to determine onset of liquid loading.

If the maps are not available for specific pressure, the user can use the interface to determine whether loading will occur or not.

Maps also have very wide applicability for well and field analysis.
Questions?
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