FLOWING GRADIENTS IN LIQUID LOADED GAS WELLS

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Acoustic fluid level data Used to Show Gradients of Gaseous Liquid Columns

- Generally In a Liquid Loaded Well When Flow Is Shut-in:
  - Liquid Holdup Decreases as Gas Rate Drops
  - Liquids Falls Back
  - Gradient of the Gaseous Liquid Column Increases

- Treating Well with Surfactant can Impact the Gradient of the Gaseous Liquid Column

- Surfactants Assist In Carrying Liquid to the Surface

- Surfactant Treatment of a Liquid Loaded Gas Wells Can Lighten the Flowing Gradient.

- If The Surfactant Treatment Rate Is Effective, Then the Flowing Gradient Can Lighten to Near a Mist Gradient
If Gas Well Flow Rate Less that 526 Mscf/D, then Liquid Loading is Predicted

Gas Velocity Removes Liquid

Liquid Loading Predicted

Qg > Qc

Qg < Qc
Range of Gradients in a Gas Well

2.375” Tubing, 0.7-SG Gas, 300 Psi Wellhead Pres

- **Qg < Qc**
- **Qg = 0**
- **Qg > Qc**

Mist Flow with 0 to 50 BWPD
Gradient 0.010 to 0.018 Psi/Ft

Gradient Range in Liquid Loaded Wells

Min Liquid Loaded Gradient 0.09 Psi/Ft

Water Gradient SG x 0.433 Psi/Ft
Echometer S-Curve

Determines Gradient Below Gas/Liquid Interface in the Gaseous Liquid Loaded Fluid Column

Qg < Qc
V_{SL} = 0

Mist \{Qg > Qc\}

Actual Field Measured Data Points

0.09 psi/ft
0.433 psi/ft

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Acoustic Fluid Level Survey in a Well Loaded With Liquid

Depth

Light Gas Gradient Above Interface

Gas/Liquid Interface

Gaseous Liquid Gradient Below

(VSL = 0
Qg < Qc)

Gas Bubbles or Slugs
Move up through Liquid Column

Pressure
**Example of Liquid Loaded Gas Well**

10000 Ft ~2.735 Tubing ~ 1000 FBHP

<table>
<thead>
<tr>
<th>Gas Rate Mscf/D</th>
<th>dp/dt Psi/Min</th>
<th>Gradient Psi/Ft</th>
<th>% Liquid</th>
<th>Gas/Liquid Interface Feet</th>
<th>L* dP/dT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.0</td>
<td>0.433</td>
<td>100%</td>
<td>8513</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>0.5</td>
<td>0.141</td>
<td>31%</td>
<td>5299</td>
<td>4271</td>
</tr>
<tr>
<td>18</td>
<td>1.0</td>
<td>0.120</td>
<td>26%</td>
<td>4395</td>
<td>8543</td>
</tr>
<tr>
<td>36</td>
<td>2.0</td>
<td>0.107</td>
<td>23%</td>
<td>3662</td>
<td>17084</td>
</tr>
<tr>
<td>72</td>
<td>4.0</td>
<td>0.097</td>
<td>20%</td>
<td>2953</td>
<td>34362</td>
</tr>
<tr>
<td>145</td>
<td>8.0</td>
<td>0.090</td>
<td>19%</td>
<td>2446</td>
<td>68518</td>
</tr>
<tr>
<td>526</td>
<td>29.0</td>
<td>0.090</td>
<td>19%</td>
<td>2446</td>
<td>248377</td>
</tr>
</tbody>
</table>
Gas Rate = 9 Mscf/D

Gas/Liquid Interface = 4701 Ft

\[ L' = (10000 - 1446) = 8554' \]

\[ dP/dT = (0.5/1) = 0.5 \]

\[ L' \times dP/dT = 4277 \]

% Liquid = 31

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Gas Rate = 72 Mscf/D

Gas/Liquid Interface = 4701 Ft

\[ L' = (10000 - 1418) = 8582' \]

\[ dP/dT = (4.0/1) = 4.0 \]

\[ L' \times dP/dT = 34320 \]

% Liquid = 20

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C, EFFECTIVE OIL FRACTION

Fg, FRACTION OF GAS IN GASEOUS LIQUID COLUMN
Liquid Loaded 10000 Ft Gas Well

Gas Column Above Liquid Level

Gaseous Liquid Column Below Liquid Level

Pressure - Psig

Well Depth - Feet

FBHP 1000 Psig
Fluid Level Measurements After Shut-in

Shots taken at approximate 5 minute intervals

Should see Mist Gradient below Fluid Level

Fluid level below tubing

Shots Down Tubing Mist \(Q_g > Q_c\)

(High Gas Velocity)
Use of Gas/Liquid Interface Depression Test

1) Dry Gas Gradient Above Liquid Level = 0.018 psi/ft
2) Mist Gradient Below Liquid Level = 0.026 psi/ft (6% Liquid)
3) Producing BHP is Extrapolated to = 804 psi

Well #1

Mist \( \{ Q_g > Q_c \} \) (High Gas Velocity)

Gas Gradients = 0.018 psi/ft

FBHP = 804 Psig

Best Fit Line = 38.451x Gas/Liquid Press - 24796
Mist Gradient = 0.026 Psi/Ft
Liquid Loaded Gas Well Acoustic Records During Shut-in

Shut-in 5 minutes

Shut-in 10 minutes

Shut-in 15 minutes

Shut-in 20 minutes

Shut-in 30 minutes

Gas/liquid interface dropped from 2392 to 6523 feet (4131 ft in 24.5 min.)

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After Shut-in Surface & BH Pressures Build as Gaseous Liquid Column Collapses

Pressure-Depth Traverses After Shut-in

Gas

Flatting Lines Show Increasing Gradient of Gaseous Liquid Column

Pressure at 7150 Ft

Collapse
Shoot Tubing and Casing

Well #3
Shoot Casing: Liquid Level @ Tubing Intake
Tubing Intake Pressure = 179.4 Psig

Well #3
Shoot Tubing: Intake Pressures must be Equal!

Total Gaseous Liquid Column HT (TVD) 4047 Ft

- **Casing Side Tubing**
  - Intake Pres = 179.4 Psig

- **Shot Down Tubing**:
  - Gas/Liquid Interface Pres = 95.6 Psig
  - Tubing Intake Pres = 548.7 Psig

- **TWM 24% Liquid w/ Gradient 0.112 psi/ft**

- **When Surfactants Used**
  - Gradients 1/3 of TWM

- **Actual Gradient**: \((179.4 - 95.6)/4047 = 0.021\) psi/ft

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**Well #3**
Flowing Gradient through the Gaseous Liquid Controlled by Gas Velocity

Pressure - Psia

Well Depth - Feet

Mist Flow with 0 to 50 BWPD
Gradient 0.010 to 0.018 Psi/Ft

Increased Gas Velocity/Rate

Min Liquid Loaded
Gradient 0.09 Psi/Ft

Water Gradient
SG x 0.433 Psi/Ft

2 3/8 In. Tubing

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Impact of Gas Rates on Gradient

Gas Rate MscfD: 0 - 8 - 17 - 36 - 73 - Turner Critical (538)

Pressure - Psia

Flowing Gradient of the Gaseous Liquid Controlled by Gas Velocity

Water Gradient SG x 0.433

Gradient Liquid Loaded Gas Wells

Min Liquid Loaded Gradient 0.09Psi/Ft

<table>
<thead>
<tr>
<th>Gas Rate MscfD</th>
<th>Psi @ 10000'</th>
<th>Gradient Psi/Ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3420</td>
<td>0.4330</td>
</tr>
<tr>
<td>8</td>
<td>1386</td>
<td>0.1489</td>
</tr>
<tr>
<td>17</td>
<td>1200</td>
<td>0.1229</td>
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<tr>
<td>36</td>
<td>1096</td>
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<tr>
<td>73</td>
<td>1019</td>
<td>0.0976</td>
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<tr>
<td>148</td>
<td>972</td>
<td>0.0911</td>
</tr>
<tr>
<td>538</td>
<td>972</td>
<td>0.0911</td>
</tr>
</tbody>
</table>
Flowing Liquid Loaded Gas Well Shut-in 1 Hour to Acquire Acoustic Shots Down Tubing

Well #4

Pressure Psi

Depth, Ft

Tubing Gas Pressure

Casing Gas Pressure

Gaseous Liquid Column Gradient

Fluid Level Determined Gas/Liquid Pressure

End of Tubing - Depth 11261 Feet
Shut-in Flowing Liquid Loaded Gas Well ~ Surface Pressure Increases From 337 to 454 Psig ~ Gas Rate Drops From 251 to 5 Mscfd ~ Less Holdup Causes Gaseous Column to Fall

Well #4

Surface Pressure Builds After Shut-in Reducing Gas Rate Causing Gaseous Liquid Column to Collapse

Fluid Level Should Follow S-Curve Gradient Line if Gas Maintains Holdup

Decreasing Gas Rate Results in Collapse of Gaseous Liquid Column Height

End of Tubing - Depth 11261 Feet
Well Flowing Below Critical Rate, Capillary Injected Surfactant Lightens Gradient to Help Well Flow

Well #5

Turner Unloading Rate for Well Producing Water

2 7/8” Tubing Well: 910 MscfD @ 840 Psig

Well Flowing Below Critical Rate
Comparison of Gaseous Liquid Column to Calculated Flowing Mist Gradient

Well #5

Fluid Level Shots Determine Distance to the Depressed Gas/Liquid Interface

Well is NOT Flowing Above the Turner Critical Rate Since Pressures at the Top of Gaseous Liquid Column DO NOT Plot near Mist Gradient Line

Calculated Mist Gradient ~ 0.02 Psi/Ft
Comparison of Gaseous Liquid Column to Echometer S-curve Gradient

Fluid Level Determined Pressures at the Top of Gaseous Liquid Column Plot along S-Curve Liquid Loaded Gradient

Well #5

1577 Psi PBHP
1692 Psi Extrapolated from Best Fit Line Through all Shots is Too High PBHP

Liquid Loaded Well Use First Few Fluid Level Shots to Extrapolate to Accurate PBHP

Best Fit Extrapolated:
Tubing Fluid Gradient = 0.106 Psi/Ft
Flowing BHP = 1692 Psig

S-Curve Liquid Loaded Gradient

115 Psi too High
1) Extra Liquid Does not appear to be accumulating in bottom of well

- Initial Plotted Gradient Matches Echometer S-Curve indicating well is liquid loaded
- If Injected Surfactant is effective, then the flowing gradient should be near mist gradient
- If the well experiences additional liquid loading while shooting a fluid level, then the gradient plot will not be a straight line.
- Accumulation of dry gas at surface reduces the height of the gaseous liquid column
- Liquid Holdup Appeared to Remain Constant during Test
Effectiveness of Surfactant Treatment

1) Flowing Pressure Gradient Plots Show:
   - Surfactant Appears To Be Providing Liquid Holdup
   - Proper Concentration Of Surfactant Should Lighten Flowing Gradient
   - In a Liquid Loaded Well Normally Gradient Increases When Flow Is Shut-in And Liquid Falls Back

2) If Liquid Level Is At The Surface, Then Liquid Appears To Be Lifted Out Of The Well

3) Proper Concentration Of Surfactant Should Improve the Well’s Performance by Reducing Gradient

4) Flowing Gradient of the Gaseous Liquid Column Can Be Modified With the Use of Surfactant
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