Acoustically Determined Gradients in Vertical and Horizontal Gas Wells

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Introduction

• Acoustic liquid level tests are performed successfully on many different types of wells throughout the world.
• In gas wells an acoustic fluid level is often acquired by “shooting” down the tubing.
• Acoustic test on a gas well can be used to determine the equivalent fluid gradient below the liquid level.
• Measurement of the mist gradients possible when well is flowing above critical.
• Liquid gradients below the liquid level on liquid loaded vertical wells is a function of the gas flow rate
• Liquid gradients below the liquid level can be determined by using a field developed correlation.
Fluid Level on Gas Well

Gas Velocity Impacts Result of Acoustic Liquid Level Shot:

1. Below Critical Velocity:
   • Usually see liquid level above bottom of tubing

2. Above Critical Velocity:
   • May not see a liquid level because liquid droplets may fill tubing and absorb all energy from shot
   • May see bottom of tubing and/or perforations due to small amount of liquid
Echometer S-Curve

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

\[ Q_g < Q_c \]
\[ V_{SL} = 0 \]

Mist \( Q_g > Q_c \)

Actual Field Measured Data Points

\[ 0.09 \text{ psi/ft} \]
\[ 0.433 \text{ psi/ft} \]

Static Fluid Level on Gas Well

- Measured Surface Pressure 2249.5 Psig
- 365.8 Psig Gas Column Pressure
- High Pressure Gas Pushed all but 87.8 ft of Liquid Back into Formation
- Easy to Observe Up-kick caused by the top perfs at 6032 feet
- Collar Recesses Counted to Perforations

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

Fluid Level Measurements After Shut-in

Shots taken at approximate 5 minute intervals

Should see Mist Gradient below Fluid Level

Fluid level below tubing
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)

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 Pres - 24796
Mist Gradient = 0.026 Psi/Ft
See a Liquid Level in Tubing when the Gas Flow is Below Critical Rate

Qg > Qc

Qg < Qc

Turner Unloading Rate for Well Producing Water

Rate (Mcf/d) vs. Flowing Pressure (psi)

- 4-1/2 OD: 3.958 ID
- 3-1/2: 2.992
- 2-7/8: 2.441
- 2-3/8: 1.995
- 2-1/16: 1.751

LL
Echometer S-Curve

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

\[ Q_g < Q_c \]

\[ V_{SL} = 0 \]

Gas flowing into well

Tested Gas Production = 265 MCF/D

FBHP = 1080.6 psi

8636’ Gaseous Height

1615’ Gas Free
If Well Becomes Loaded, then Pressure at any Depth in a Gaseous Liquid Column is Independent of Surface Pressure (Dropping Surface Pressure May Not Remove Liquid Loading)
End of the tubing near the bottom of the perforations, then increasing casing pressure tends hold liquid in the tubing.

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

Shut-in 5 minutes

Shut-in 10 minutes

Shut-in 15 minutes

Shut-in 20 minutes

Shut-in 30 minutes

Acoustic Records After Shut-in of Loaded Gas Well

Well #2
After Shut-in Increasing Pressures Reduces Gas Rate to Collapse Gaseous Liquid Column

Pressure-Depth Traverses After Shut-in

Flatting Lines Show Increasing Gradient of Gaseous Liquid Column

Pressure at 7150 Ft
Accumulating Gas Pushes Liquid Out of Tubing Without Impacting Gas Rate From Formation

End of Tubing Set Above the Kickoff Point OR Above All Perforations

Depth - Ft
Tubing Fluid Gradient Remained **Constant** as Gaseous Liquid Pushed Out

If Gas Rate into Tubing Drops then in Liquid Loaded Well the Liquid Column Collapses when Tubing Shut-in

Tubing Fluid Gradient 0.0627 Psi/FT

Tubing Set High
Tubing Fluid Gradient Remained *Constant* as Gaseous Liquid Pushed Out

If Gas Rate into Tubing Drops then in Liquid Loaded Well the Liquid Column Collapses when Tubing Shut-in

Tubing Fluid Gradient 0.0627 Psi/FT

Tubing Set High
In Horizontal Wells Stratified Flow Exists
Its Common to see Features Past EOT

GLV 1 @ 1712'
GLV 2 @ 3014'
GLV 3 @ 4092'
GLV 4 @ 4797'
GLV 5 @ 5256'
GLV 6 @ 5716'
GLV 7 @ 6176'
GLV 8 @ 6570'
GLV 9 @ 7031'

Tubing Depth: 7588.90 ft
Toe 9610 ft

Gas Lift Valves Used To Confirm Up Kick Selected is the Top Of Perfs
Can Shoot to Toe Due to Stratified Gas Flow in Horizontal

1. Gas gun was charged to 800 psi to create this shot. (CP=226 Psig)
2. Red line and valve number identify the gas lift valves echoes on the acoustic trace.
3. Top perf up kick echo was used to determine the depths in the well.
Turner Angle Modification (TNO-Shell)

TNO/Shell Modification for Hole Angle

35% increase at 37°
6 Shots Fluid Level Depression Test in Horizontal Liquid Loaded Gas Well

EOT – 7831 MD

7096 MD LL – 05/06/2015 02:16:07 PM

8763 MD LL – 05/06/2015 02:33:44 PM
Gradient = 0.178 Psi/ft

Height = -5.5928xPsi + 3073.3
Liquid Loading Below Kick-Off in Horizontal Well

• Shutting in Liquid Loaded Horizontal Well for 17 minutes, resulted in Liquid Load being Pushed Out of Tubing

• At End of Test the Liquid level was far Below EOT, Likely due to Stratified Flow in Horizontal Section

• Gradient in Tubing below Kick-off is 0.178 psi/ft, which is >two times normal 0.08 psi/ft in a Vertical Gas Well

• Liquid in Tubing Below Kickoff Represent Significant Amount of Loading

• Use 50-60% of Tubing Measured Depth Below Kickoff to Estimate Vertical Liquid Load
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