Acoustic Liquid Level Testing of Gas Wells

O. Lynn Rowlan and James N. McCoy
Acoustic Fluid Levels

- Traditionally Fluid Level shot down the Casing Annulus
- Most Often In Oil Wells
- Tubing collars are counted to determine depth
- Operators shoot the well to determine
  - Producing and Shut-in BHP
  - Well’s Producing Rate Efficiency
  - Maximum Production Potential
What is an Acoustic Fluid Level

- Generate Blast at Surface to Create Traveling Wave
- Acoustic Wave Travels in casing (and/or tubing) annulus at Speed of Sound
- Echoes RTTT from well bore change diameter recorded
  - Reduction seen as a down-kick
  - Increase is seen as an up-kick
  - Fluid level gives large kick and lets almost no energy through
Initial Acoustic Pulse – caused by explosion of compressed gas into the tubing or casing annulus, explosion into annulus forms compression traveling wave.

Reflected Pulse – caused by DECREASE in the annular cross-sectional area IS displayed as an downward kick on the acoustic trace.

Reflected Pulse – caused by INCREASE in the annular cross-sectional area IS displayed as an upward kick on the acoustic trace.

Acoustic Trace Acquired down the Tubing Showing Upkick from Hole in Tubing
Fluid Level in Gas Well

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
Look in Well with Acoustic Survey to see What is Downhole

@ 4750 Ft
Tight Spot in Tubing
Bumper
Spring

@ 4325 Ft
1/8 x 1/4 in.
Small Hole in Tubing
Gas Gun Physical Set-up on Well
Acoustic Trace with Depth Determination

Liquid Level Depth (LL)
Collars count depth (C) is noted on the acoustic signal.

1 Sec

Acoustic Trace with Depth Determination
Default: Automatic Collar Count
Downhole Marker Using Known Perforation Depth to Determine Distance to the Liquid Level

```
? = 1875 ft
```

```
2.631 sec
```

```
1369 ft
```

```
1.921 sec
```

```
1.921 sec
```

```
1369 ft
```

```
32.610 ft
```

```
41.981
```

```
Perfs: 1369-71; 1530.5-33.5; 1807.5-09.5
```

```
Liquid Level Depth: 1874.98 ft
```

```
Acoustic Velocity: 1425.3 ft/s
```

```
Calculate
```

```
Done
```

Depth Determination:  

**Acoustic Velocity** method

Acoustic Velocity options:
- □ Manually entered
- □ Calculated based on SG of gas
- □ Calculated based on compositional analysis

(Manual gas velocity can be used for approximations or in case where velocity already determined by downhole marker correlation in other shot)

Depends on:

1. Gas gravity / composition
2. Temperature along completion
3. Pressure in the completion (automatically calculated from measurements taken during the shots)
4. May use Casing Shot for Tubing SG
Gas flowing into well

Tested Gas Production = 265 MCF/D

FBHP = 1080.6 psi

8636’ Gaseous Height

1615’ Gas Free

Closed Valve 2.5 Min. to Determine Gas Flow Rate and % Liquid
Gas flowing into well

$61.7 \text{ psi}$

$3427'$

$Da \times \frac{dP}{dT} = 61813$

$Da = 9719$

Determine % Liquid

$1615'$

Gas Free
Backpressure in a Liquid Loaded Well

Liquid Level

![Graph showing liquid gradient and gas gradient with depth and pressure values.]

<table>
<thead>
<tr>
<th>Select Liquid Level</th>
<th>Depth Determination</th>
<th>Tubing Pressure</th>
<th>BHP</th>
<th>Collars</th>
<th>De-Liquification</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Current</th>
<th>Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil</td>
<td>1.2</td>
</tr>
<tr>
<td>Water</td>
<td>0.8</td>
</tr>
<tr>
<td>Gas</td>
<td>265.0</td>
</tr>
</tbody>
</table>

Based on SBHP: 2640.4 psi (g)

IPR Method: Vogel

Calculation for Continuous Removal of Liquids:

Method: Turner Critical Velocity for Gas Wells

- For Tubing ID: 2.441 in
- For Water: 980.1 Mscf/D
- For Condensate: 632.9 Mscf/D

Back Pressure on Formation:

- Due to Liquid Loading: 621.924 psi

<table>
<thead>
<tr>
<th>Tubing ID</th>
<th>Gas Rate</th>
<th>Predicted Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.441</td>
<td>265.0</td>
<td>Loaded</td>
</tr>
<tr>
<td>1.995</td>
<td>265.0</td>
<td>Loaded</td>
</tr>
<tr>
<td>1.500</td>
<td>265.0</td>
<td>Loaded</td>
</tr>
<tr>
<td>1.250</td>
<td>313.4</td>
<td>Flowing</td>
</tr>
<tr>
<td>1.000</td>
<td>304.2</td>
<td>Flowing</td>
</tr>
</tbody>
</table>
Types of Gas Well Surveys

- **Liquid Level Moves w/ Change in Pressure**
  - Well is producing and Shots taken as liquid level (interface) moves
  - Flowing Gradient and BHP Determined

- **Liquid Does not Move - Static Shut-in Well**
  - Acquire a few shots at static conditions

- **Pump Liquid into Well**
  - Pump something in the well that moves (surfactant, corrosion inhibitor)
  - Track the top of the liquid slug down the wellbore

- **Liquid level in Casing/Tubing Annulus**
  - Casing/Packer/Tubing Integrity Testing
  - Trouble Shoot Well – Kicks do not Belong
Summary for transient liquid level shots

- Well must be in production until ready for shots
  - Gaseous liquid column can move quickly and go below end of tubing
  - Requires good communication with operations for planning
- Start with relatively high pressure in gas gun for shots to have best chance of seeing deep into low pressure wells
- Complete Well Data important in further analysis
- FBHP calculation is reasonably accurate
Fluid Level Measurements After Shut-in

Shots taken at approximate 5 minute intervals

Should see Mist Gradient below Fluid Level

Fluid level below tubing

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

1) Dry Gas Gradient Above Liquid Level = 0.0179 psi/ft
2) Mist Gradient Below Liquid Level = 0.029 psi/ft (6% Liquid)
3) Producing BHP is Extrapolated to = 804 psi

Gaseous Column Height vs. Pressure from Fluid Level Data
Gas Well Type – 1 (High Gas Velocity)

Regression Equation
Column Height = -33.968*Pressure + 27293

Gaseous Column Gradient = 0.029 psi/ft

PBHP = 804 psi
## Liquid Loaded Gas Well

### Before Running Tools
- **Gas/Liquid Interface = 3626’**

### Tools at 2500 ft
- **Gas/Liquid Interface = 3332’**

### Tools at 5000 ft
- **Gas/Liquid Interface = 3165’**

**Acoustic Velocity Determined from Tubing Collar Recess Echoes**

*Very Similar to the Acoustic Velocity Determined From Echo at Top of Tool*
Static Fluid Level Shots

• Tubing:
  – Well is shut-in
  – Shoot multiple shots down tubing
  – Shot traces should repeat
  – Assuming no pressure increase, only a few shots are required to verify that traces repeat

• Annulus:
  – Attach Gun to annulus
  – Shoot a couple of shots and go to next well
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

Shut-in Gas Well
Shot Down Tubing or Casing
Verify Liquid Level Above/Below Tubing Inlet

End of Tubing
Summary for Pumping Jobs

• Take baseline shot to establish an acoustic velocity before pumping (helps to know depth while job going on)
• Plan on being there for at least a few hours if not all day
• Be patient, liquid level will not be clear at first
• High pressure in the gun is not required for the initial, high liquid levels.
• Fluid level is indication of top of liquid, bottom of liquid could be much lower depending on amount pumped and how much it spreads out in well
Gas Lift Mandrel is Easily Seen by Application of Low Pass Filter

High Frequency Noise

See Downhole Anomalies:

SCSSV@ 1575
X-NIPL@ 3161
GLM1@ 3618
GLM2@ 11743
BHP Ch@ 11798
CIM@ 11874
X-NIPL@ 11993
XO@ 12041
XN-NIPL@ 12374

Liquid Level

SCSSV

GLM1

Apply Low Pass Filter
Liquid Level Near Surface

0.27 Sec ~ 165 Ft.

0.105 Sec ~ 63.5 Ft.
Liquid Soap Treatment – Acoustic Shots
Surfactant Initially Fell @ 18 Ft/min

After 22 Min.
Top of Soap
316 feet from
Surface

After 23.4 Min.
See thru Soap
359 feet from
Surface

Soap Fills Tubing
While Falling

Liquid Soap

Soap is Falling as a Tube

EC Martinez No 4
Fluid Level Results on Gas Well Treated with Surfactant – Foam 1/3 of Gaseous Liquid Gradient

? - %Liquid
Holes in Tubing

• DO NOT be surprised if more than 10% of your liquid loaded gas wells have holes in the tubing.
• Hole Causes Significant Drop in Gas Production.
• Tubing and Casing Pressure are Not Equal with Hole
• When flow up tubing; High Fluid Level in Casing Likely Indicates a Hole in the Tubing
• High Cost of using a wire-line to set a standing valve and pressure test the tubing may be avoided
• Using an acoustic fluid level instrument is a low cost, quick method to troubleshoot a gas well and to identify the presence/location of a hole.
Use an Acoustic Fluid Level Instrument To Identify The Depth To The Hole

1. Shoot tubing/casing annulus while flowing up tubing
   - Fluid Level should be near tubing intake or below perforations (If no Hole)
Small hole began to cause problem.

Drop in production due to liquid loading?

Shot fluid levels to open sliding sleeve and commingle two zones.

Found hole in tubing with fluid level shot.

Dramatic drop in rate: 820 Mscfd → 250 Mscfd.

Replaced tubing and gas flow returned to 2006 rate.

Turner critical: 320 McfD.
Can’t be a Hole ~ Tubing is New
Hole @ Depth 4325 Ft from Surface
Hole Not Visible

Time 12:12:27 Csg 125.9 Psi
Shot Casing/ Flowing Up Tubing

Time 12:24:15 Csg 135.5 Psi
Shot Casing/ Tubing Flow Shut-in

Time 12:29:14 Csg 138.8 Psi
Shot Casing/ Tubing Flow Shut-in

Time 12:35:58 Tbg 143.1 Psi
Shot Tubing/ Flow Shut-in

Time 13:09:38 Tbg 150.8 Psi
Shot Tubing/ Flow Shut-in

Hole @4325 Ft
<table>
<thead>
<tr>
<th></th>
<th>Packer Integrity Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Identify Wells w/ Increased Annulus Pressure</td>
</tr>
<tr>
<td>2.</td>
<td>DO NOT BLEED OFF PRESSURE</td>
</tr>
<tr>
<td>3.</td>
<td>Pressure at the packer was equal from the fluid level shot down the Tubing and Annulus.</td>
</tr>
<tr>
<td>4.</td>
<td>Equal pressure at the packer indicates that the packer assembly is the likely cause of the gas leak from the tubing into the casing annulus.</td>
</tr>
<tr>
<td>5.</td>
<td>After bleeding pressure ~ Leak recharge rate through the packer is 15 MscfD, when the casing pressure was dropped from 92 psi to zero (resulted in a 92 psi pressure differential across the packer.</td>
</tr>
<tr>
<td>6.</td>
<td>15 MscfD is a slow recharge rate and this leak through the packer may be considered minor.</td>
</tr>
</tbody>
</table>
Casing Annulus pressure buildup rate of 3.2 psi in 15 minutes is due to an average of 15 Mscf/D of gas flowing though the pressure leak over the 15 minute time interval.
## Summary

<table>
<thead>
<tr>
<th>Type of Survey</th>
<th>Current Process</th>
<th>Advantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Determine liquid Level and BHP in Liquid Loaded Gas Well</td>
<td>Flowing Pressure Gradients on Slickline</td>
<td>Save Day(s) of Wireline, crew, and equipment</td>
</tr>
<tr>
<td>Flowing Gaseous Column Gradient</td>
<td>Flowing Pressure Gradients on Slickline</td>
<td>Save Day(s) of Wireline, crew, and equipment</td>
</tr>
<tr>
<td>Static BHP and Fluid Level ~ Maximum tubing set Depth</td>
<td>Slickline / not done</td>
<td>Save Day(s) of Wireline, crew, and equipment</td>
</tr>
<tr>
<td>Liquid Level in Annulus</td>
<td>Calculations based on N2 Injected</td>
<td>More Accurate Information</td>
</tr>
<tr>
<td>Integrity Testing of Annulus</td>
<td>Calculations based on N2 Injected</td>
<td>Determine Gas Leak Rate</td>
</tr>
<tr>
<td>Locate Holes in Tubing/Casing</td>
<td>Slick Line set SV and Pressure test</td>
<td>Save Day(s) of Wireline, crew, and equipment</td>
</tr>
<tr>
<td>Monitor Effectiveness of Batch Treatment</td>
<td>Not previously possible</td>
<td>Increase Production Rate</td>
</tr>
<tr>
<td>Track fall rate of plunger, batch corrosion and foam jobs</td>
<td>Slickline/Not possible</td>
<td>Save Day(s) of Wireline, crew, and equipment</td>
</tr>
<tr>
<td>Gain understanding of liquid loaded well behavior</td>
<td>Not previously possible</td>
<td>Increase Production Rate</td>
</tr>
<tr>
<td>Confirm SSSV Close/Open Operation</td>
<td>Slickline</td>
<td>Save Day(s) of Wireline, crew, and equipment</td>
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</table>
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