Adjustments to Plunger Fall Velocity Due to Change in Gas Flow Rate

O. Lynn Rowlan & James N. McCoy - Echometer Company
Introduction

• Acoustic instrument acquisition of surface acoustic and/or pressure measurements effectively determines a plunger’s fall velocity.
• Measured plunger fall velocity at pressure and temperature at a specified tubing depth is used to determine the Plunger Fall Performance Coefficient, C.
• The expected plunger fall velocity at a specific depth is equal to C divided by the square root of the gas density at the specific depth in a well.
• A particular type of plunger has a specific performance
• The Plunger’s C is used to calculate the plunger’s expected velocity at any/all other depth, pressure and temperature in the well
During Shut-in: Record Plunger Acoustic Signal & Tubing Pressure

1) Acoustic
   - Plunger Depth
   - Plunger Velocity
   - Gas SG

2) Tubing Pressure
   - Pressure
   - Density
   - Gas MscfD

Just Listen To Plunger

Feb. 20 - 22, 2017
2017 Gas Well Deliquification Workshop
Denver, Colorado
What is Recorded During Shut-in Time Period When the Flow Line Motor Valve is Closed

- **Shut-in Begins**
- **Casing Pressure Increases**
- **Shut-in Ends**
- **Quieter when Plunger on Bottom**
- **Uniformly Spaced Tubing Collar Acoustic Reflections**
- **Tubing Pressure Increases**

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Determine Plunger Fall Speed Between Two Consecutive Collar Echoes

Plunger Velocity @ Joint 127 equals the change in depth divided by the change in elapsed time.

\[ \text{Velocity} = \frac{D_i - D_{i-1}}{T_i - T_{i-1}} = -234.05 \text{ ft/min} \]

Looking at this Minute

Falling through Gas

Avg. Plunger Vel. (Gas) = -239.45 ft/min

Each Joint
Measure Plunger Fall Velocity in Well

Velocity and Depth Graph

Collar # C46
Depth To Plunger: 1481.20 ft
Plunger Fall Velocity: -185.77 ft/min
Elapsed Time: 09:20:01 AM
clock

Click on Any Point

Falling through Gas Gradually Slows from 240 ft/min to 135 ft/min

Normal Fall Velocity Profile
1) Tubing is OK
2) Liquid in Bottom

Falling thru Liquid

Plunger Hits Liquid: 7312 ft

Bottom of Tubing: 1773 ft
General Plunger Velocity Fall Model
Derived From the Drag Equation

Step 1
\[ Cd \times A = Wt \times 2gc/(\rho V^2) \]

Step 2
\[ V = \sqrt{\frac{2Wt \, gc}{(CdA)}} \]

Step 3
\[ V = C / \sqrt{\rho} \]

Where
\[ C = \sqrt{\frac{2Wt \, gc}{(CdA)}} \]

Echometer Plunger Fall Performance Coefficient: \( C \)
Measured Fall Velocity in 40 Different Wells for Identical Manufactured Cleanout Plunger

<table>
<thead>
<tr>
<th>Average Fall Pressure (psi)</th>
<th>Measured Average Fall Velocity (ft/Min)</th>
<th>Model Average Fall Velocity (ft/Min)</th>
<th>Difference Measured - Model (ft/Min)</th>
<th>Model’s Absolute % Error</th>
</tr>
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<tbody>
<tr>
<td>140</td>
<td>296</td>
<td>412.9</td>
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<td>53</td>
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<td>265</td>
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<td>234</td>
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<td>152</td>
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<td>53.6</td>
<td>18.4</td>
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<td>293.5</td>
<td>65.5</td>
<td>18.2</td>
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<td>370</td>
<td>331.0</td>
<td>39.0</td>
<td>10.5</td>
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</tbody>
</table>

Avg Error = 0.7 Ft/Min
Avg Abs Error = 11.7%
Abs Avg Error = 40.1 Ft/Min
1. Input Average Known Fall Velocity at P & T to Calibrate Model

2. For Fall Velocity Calculation Specify Pressure Range

3. Click Calculate Fall Velocity Button to Plot Calculated Fall Velocities

4. Go to Output Worksheet to see Plot
New General Plunger Fall Model Predicts Plunger’s Fall Velocity at Density for Pressure and Temperature

Lab Measured Cleanout Plunger Fall Velocity at 17.3 Psia of 1352.5 Ft/Min

Model Input: 300 Ft/Min @ 261.7 Psia

\[ V = \frac{C}{\sqrt{\rho}} \]
<table>
<thead>
<tr>
<th>Plunger Description</th>
<th>Picture</th>
<th>Avg Fall Velocity, Ft/min</th>
<th>Avg Pressure, Psia</th>
<th>C</th>
</tr>
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<tbody>
<tr>
<td>Dual Pad w/ Seal</td>
<td><img src="image" alt="Dual Pad w/ Seal" /></td>
<td>-236.6</td>
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</table>

\[ V = C \div \sqrt{\rho} \]
Predicted Plunger Fall Velocity at Different Pressure Using [C] for Different Plungers

\[ V = \frac{C}{\sqrt{\rho}} \]
Measured Plunger Fall Velocities Compared to Predicted Fall Velocity by

\[ V = \frac{C}{\sqrt{\rho}} \]

- Plunger Fall Velocity
- Plunger Depth

Elapsed Time - Mins

- Only Gas
- Gas & Liquid
- Gas & Liquid & SV
  Opens / Closes

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Use C and Gas Density to Predict Plunger Fall Velocity versus Well Depth

Average Absolute Error = 15.5 Ft/Min
6.6% Percent Average Error
When Tubing Pressure is Flat then SV is on Seat and NO Gas Enters the Tubing

Plunger Velocity Decreases by ~ 68 Ft/Min When SV Opens

Gas & Liquid Enter When SV Opens
Change in Plunger Fall Velocity Directly Related to Change in Low Gas Flow Rate

When SV Opens Instantaneous Gas Inflow Reduces Plunger Fall Velocity

68 Ft/Min

32.3 MscfD

0 MscfD

32.3 MscfD = 78.8 Ft/min @ 5800 Ft @ 219 Psia
Well 1 - Echometer Plunger Fall Performance Coefficient \([C] = 196.9\)

**Laminar Flow < 100 Ft/Min?**

**Turbulent Flow**

Bottom of Tubing: 8081 ft
Plunger Hits Liquid: 7993 ft

% to Show Collars at End: 94%

### Table

<table>
<thead>
<tr>
<th>#</th>
<th>Time</th>
<th>Measured Velocity</th>
<th>Depth</th>
<th>Measured Surface Pressure</th>
<th>Temp @ Depth</th>
<th>Pressure @ Depth</th>
<th>Gas Density</th>
<th>(C)off</th>
<th>Predicted Calc Velocity</th>
<th>Tubing Gas Velocity</th>
<th>Relative to Gas Flow</th>
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<td>3171.11 ft</td>
<td>155.3 psi (g)</td>
<td>98 deg F</td>
<td>168.6 psi (g)</td>
<td>0.6839 lb/ft³</td>
<td>196.03</td>
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<td>98 deg F</td>
<td>168.7 psi (g)</td>
<td>0.6840 lb/ft³</td>
<td>199.44</td>
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<td>70.5 ft/min</td>
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<td>C105</td>
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<td>-233.07 ft/min</td>
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<td>155.6 psi (g)</td>
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<td>169.2 psi (g)</td>
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<td>-236.83 ft/min</td>
<td>51.5 ft/min</td>
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Collar: C103
Echometer Plunger Fall Performance Coeff (C): 196.03 Average for Well (C): 196.90
Gas Density(p): 0.6839 lb/ft³ @ 98 deg F @ 168.6 psi (g)
Gas Velocity: 63.2 ft/min
Well 2 - Echometer Plunger Fall Performance Coefficient [C] = 215.16

Plunger Hits Liquid: 7282 ft
Bottom of Tubing: 7798 ft

<table>
<thead>
<tr>
<th>#</th>
<th>Time</th>
<th>Measured Velocity</th>
<th>Depth</th>
<th>Measured Surface Pressure</th>
<th>Temp @ Depth</th>
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<th>Gas Density</th>
<th>(C)oeff</th>
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<td>-205.25</td>
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</table>

Collar: C121
Echometer Plunger Fall Performance Coeff (C): 214.18 Average for Well (C): 213.89
Gas Density(p): 1.0889 lb/ft³ @ 128 deg F @ 292.9 psi (g)
Gas Velocity: 14.3 ft/min
Well 3 - Echometer Plunger Fall Performance Coefficient [C] = 192.79

Plunger Hits Liquid: 2950 ft
Bottom of Tubing: 3473 ft

<table>
<thead>
<tr>
<th>#</th>
<th>Time</th>
<th>Measured Velocity</th>
<th>Depth</th>
<th>Measured Surface Pressure</th>
<th>Temp @ Depth</th>
<th>Pressure @ Depth</th>
<th>Gas Density</th>
<th>(C)eff</th>
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Collar: C49
Echometer Plunger Fall Performance Coeff (C): 207.64 Average for Well (C): 192.79
Gas Density(p): 0.1025 lb/ft³ @ 91 deg F @ 24.5 psi (g)
Gas Velocity: 102.0 ft/min
Gas and Plunger Velocity Related

When Velocity is Low then Drag Forces are High, Plunger Velocity Impacted by Laminar Gas Flow

Laminar Flow

Turbulent Flow
Optimize Plunger in Well

- Published fall velocity for a plunger type are NOT accurate, because fall velocity is significantly impacted by gas density.
- Using Measured Plunger Fall Velocity with the Model to Predict Plunger Fall Velocity at other P & T.
- Changing the Plunger Cycle Impacts Operating Pressure, Model Calculates Velocity at New P & T.
- Each plunger type has its own Performance Coefficient
- When changes to the well cycle impact the operating pressure, use model to determine the change in time required for the plunger to fall to bottom during shut-in.
Conclusions

• All plungers have faster fall velocity at low pressure vs slower fall velocity at high pressure (Gas Density).

• Gas Density and $C$ are used to Predict Plunger Fall Velocity through Gas at any P & T in the Tubing

• BUT, Plunger Velocity Relative to the Tubing Changes as the Upward Velocity of the Gas Changes – When Gas Velocities are Slow

• Gas Flow Impact on Plunger Fall Velocity is Negligible when Gas Flow is Turbulent

• Plunger Fall Velocity Directly Impacted when Gas Flow is Laminar when Gas Flow Rates are Slow
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