Plunger Fall Velocity Model

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What’s known about Plunger Fall Velocity

1. Diameter of Plunger – Larger Diameter Falls Slower
2. Effectiveness of Seal between Plunger and Tubing – Better Seal Plunger Falls Slower
3. Brush stiffness – If the Bristles do not provide an effective seal then the plunger falls faster
4. Increased friction due to contact with the tubing – Plunger Falls Slower
5. Old age/increased wear – as the plunger wears out the worn plunger falls faster
6. If Gas can pass through plunger (i.e. Bypass) – then a plunger falls faster
7. When the plunger becomes stuck and stops – usually indicated by a 3 psi increase in pressure
8. If the Tubing is Sticky – the plunger falls slower
9. Wellbore Deviation – more than 20 degrees of deviation impacts plunger fall velocity
   a. Padded Plungers Faster due to Loss of Seal
   b. Solid Plungers Slower due to Increased Friction

10. Gas Flow Rate Into The Tubing – gas flow into tubing reduces plunger fall velocity

11. Pressure ~ Density of Gas
   a. High Pressure and plunger fall is Slow
   b. Low Pressure and plunger fall is Fast

12. Liquids increase density – plunger falls slow
   a. Surfactant lightens gradient and plunger falls faster, but more time may be required
   b. High pressure also causes plunger to fall more slowly through liquid
Manufacturer Designed Brush Stiffness and Seal Impact Fall Velocity

New Brush Fall Velocity Ranges from 160 – 425 Ft/Min

WPX Energy

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Develop Plunger Fall Velocity Model

• Models Predicts Fall Velocity In Well at Any Pressure Conditions and Temperature
• All Plungers Generally Fall Fast At Low Pressure and Slow At High Pressure
• Use Known Fall Velocity at a Specific Pressure And Temperature to Calculate Fall Velocity At Other Pressures And Temperatures.
• Published Fall Velocities Can Be Used For Each Plunger Type ~ But May Not Be Accurate For Other Conditions
• Data From Many Wells Will Be Used To Compare The Measured Fall Velocity Of Different Types Of Plungers To The Predicted Fall Velocity.
Due to Gravity the Plunger’s Weight Pushes Through Gas at a Velocity

Pressure Drop = \( \frac{\text{Weight}}{\text{Area}} \)

Pressure Drop = 2.4 psi

Plunger weight (8 lbs) / Area of 2-3/8”
Plunger Fall Velocity Models

Drag Model: Set Plunger Weight to Drag

\[ C_d \rho AV^2 / (2gc) = W_t \]

Orifice Model

\[ (C_d_{Ann}) \sqrt{\left( \frac{2W_t gc}{(A \rho)} \right)} = V A \]

Flow through the plunger/tubing area
**Drag Model** for Specific Plunger in a Well at Constant Mass Flows Past the Plunger

@ P & T and a measured Fall Velocity Calculate:

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

**Cd** - Drag Coefficient  
**A** - Area of Tubing  
**V** - Plunger Fall Velocity  
**Wt** - Weight Plunger  
**\( \rho \)** - Fluid Density  
**gc** - Gravitational Constant

Kinetic Energy \( \sim \) Plunger’s Weight pushes on gas and Velocity Changes to Pass Constant Fluid Mass Past Plunger @ P & T

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Orifice Model for Specific Plunger in a Well a dP Across Plunger Supports Weight

@ P & T and a measured Fall Velocity Calculate: Cd x Ann – dP Required to Support Plunger Fall

\[ Cd \times Ann = \frac{V \times A}{\sqrt{(2 \times Wt \times gc) / (A \rho)}} \]

Cd - Drag Coefficient
Ann - \(\pi \times (\text{Tubing ID}^2 - \text{Plunger OD}^2)/(4 \times 144)\)
A - Area of Tubing
V - Plunger Fall Velocity
Wt - Weight Plunger
\(\rho\) - Fluid Density
\(gc\) - Gravitational Constant

Plunger Acts as a Choke where dP Across Plunger Supports Velocity @ P & T
Knowing Mass Pass Plunger Constant then Determine Plunger Fall Velocity @ New P & T

For Drag Model: Use CdxA
For Orifice Model: Use CdxAnn

Use Model Equation to Calculate @ Any Desired P & T:
1) New Gas Density – ρ
2) New Plunger Fall Velocity (Ft/Min) - V
General Model:

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

Compare Orifice Model to Drag Model
1. Data used to correlate construction features of plungers to fall velocity
2. Some features cause a plunger to fall rapidly, while other features cause a plunger to have a slower fall velocity.
3. Well conditions (gas flow rate and pressure) have significant impact on plunger fall velocity.
4. Use plunger fall velocities to determine shut-in time
   a. Using 1 Velocity for a Plunger type may not be accurate
   b. Impacted by many parameters
How: Listen to Plunger Signals During Shut-in

Shut-in: Surface valve closed, flow shut-in, plunger falls down the tubing. Goal of the operator or controller is to try to achieve Shut-in of the well for the shortest amount of time possible, But long enough for plunger to reach bottom. And long enough for the pressure to build high enough to bring the plunger back to surface.

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Equipment on Well
[A] Valve Closes, Shut-in Begins and Pressure Starts Increasing

[B] Valve Opens, Unloading Begins

[C] Valve Closes, Cycle Repeats

[D] Plunger Arrives, Tubing Pressure Spike Maximum, After-flow begins
Pressures During Normal Well Cycle
500,000 Data Points Collected in 90 Min.

[A] Valve Closes, Shut-in Begins and Tubing Pressure Starts Increasing
1. Plunger hits Liquid
2. Plunger on Bottom

[B] Valve Opens, Unloading Begins
3. Liquid Arrives, Tubing Pressure at Minimum
4. Plunger Arrives, After-flow begins, Tubing Pressure Maximum Spike

[C] Valve Closes, Cycle Repeats

Casing Pressure
Acoustic Signal
Tubing Pressure

Time - Minutes
Velocity: Plunger Fall Speed Between Two Consecutive Counted Collars

Plunger Velocity @ Joint 22 equals the change in depth divided by the change in elapsed time.

Velocity = \( \frac{D_i - D_{i-1}}{T_i - T_{i-1}} \) = -230.9 ft/min

Looking at this Minute Falling through Gas Each Joint

\( D_{i-1} = 676.2 \)  \( D_i = 708.4 \)

\( T_{i-1} = 5.663 \)  \( T_i = 5.802 \)
Normal Fall Velocity [During Shut-in]

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

Faster

Slower

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

Falling thru Liquid

Click on Any Point

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Fall Velocity is Faster at Low Pressures Slows as Pressure Increases

Dual Pad Plunger

Fast

Slower

Plunger Velocity - (ft/min)

Tubing Pressures - (psi (g))

Elapsed Time - minutes

Plot Increment 3 sec X-Axis Range: 44.000 mins Full Trace

Bypass Slows at High Pressure
Shut-in Time needs to be 2.66 Hours

2.375” Dual Pad Bypass Plunger when Tubing Pressure 1732 to 2213 Psig

Avg Velocity 78.4 ft/min

Normally Dual Pad Bypass Plunger Fall > 1000 Ft/Min
Fall Velocity Different in Gas and Fluid Due to Density

201 Ft/min Gas

38 Ft/min Liquid

Plunger Hits Liquid

Plunger on Bottom

Fall Velocity in Liquid

Gassy Fluid: 38 Ft/min
Surfactant: 80 Ft/min
High Pressure: 23 Ft/min

Only Shut-in Time Period Shown
Fall Velocity Increases as Pressure Decreases

Dual Pad Plunger Fall Velocity Faster 1.75 Ft/Min with Each 1 Psi decrease in Pressure
Use Known Velocity and Pressure to Predict Plunger Fall Velocities in Same Well

Model Input: 394.8 Ft/Min @ 88.0 Psia

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Measured Fall Velocity From 40 Different Wells

Cleanout Plunger Fall Velocity Calculation Based on Gas Density Model at Pressure and Temperature

Model Input:
300 Ft/Min @ 261.7 Psia

Avg Error = 1.3 Ft/Min
Abs Avg Error = 40.1 Ft/Min
Conclusions

• From Know Plunger Fall Velocity Use Model to Predict Fall Velocity at other P & T.

• Acoustic Instrument Is An Effective Method To Measure Fall Velocity and Provide Input Into the Model.

• Changing the Plunger Cycle Impacts Operating Pressure, Model Calculates New Shut-in Time.

• Knowing Fall Velocity Will Ensure That The Plunger Will Reach Bottom By The End Of The Shut-in Period.
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