Plunger Pressure Requirements and Flow Capabilities

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Foss/ Gaul Model


2. Modified Foss and Gaul model used in this study.

3. Show Impact of Low Line Pressure when Producing Gas Wells

4. Prediction accounts for liquid load, frictional effects, tubular sizes and lengths, surface line pressure and fluid properties.
Concept of F&G Model: Original

Foss and Gaul based on Ideal Gas Law

\[ P_1 V_1 = P_2 V_2 \]

**Pc, max when well ready to open**

**Casing Volume Only**

**Pc,min, slug and plunger surface**

**Casing & Tubing volume**

\[ P_1 = Pc,\text{max} \text{ (Pressure Valve Opens)} \]

\[ Pc,\text{max} = \frac{V_2}{V_1} P_2 \]

\[ Pc,\text{max} = \frac{(Acsg+Atbg)}{(Acsg)} \times P_2 \]

\[ Pc,\text{max} = \text{CPR} \times Pc,\text{min} \]

**P2 = Pc,\text{min} \text{ (Pressure Plunger Arrives)}**
Equations Used in Derivation

Appendix A: Foss and Gaul Equations: Original and Modified

## Combined Foss and Gaul and Rule-of-Thumb-Calculator:

Manually input bbls in tubing, otherwise 0

<table>
<thead>
<tr>
<th>Input US Oilfield &amp; Calculate Same</th>
<th>2.00 bbls</th>
<th>0.32 m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tbg ID, ln input 1.995 2.441 or 2.992</td>
<td>2.441 in</td>
<td>6.20 cm</td>
</tr>
<tr>
<td>Casing ID, inches</td>
<td>4.09</td>
<td>10.39 cm</td>
</tr>
<tr>
<td>Average Well Temp, F</td>
<td>130.00 F</td>
<td>54.44 cm</td>
</tr>
<tr>
<td>Pcs, psi</td>
<td>1240.56 psig</td>
<td>8552.42 kpa</td>
</tr>
<tr>
<td>Ptbg, psi</td>
<td>1090.86 psig</td>
<td>7520.39 kpa</td>
</tr>
<tr>
<td>Pp, psi to lift plunger wt, lbs</td>
<td>5.00 psig</td>
<td>34.47 kpa</td>
</tr>
<tr>
<td>Line Pressure, psi</td>
<td>400 psig</td>
<td>2757.60 kpa</td>
</tr>
<tr>
<td>Liquid SG</td>
<td>1.00 dimless</td>
<td>1.00 dimless</td>
</tr>
<tr>
<td>Gas Gravity</td>
<td>0.65 dimless</td>
<td>0.65 dimless</td>
</tr>
<tr>
<td>Plgr Fall Vel in Gas, ft/sec</td>
<td>250.00 ft/min</td>
<td>76.20 m/min</td>
</tr>
<tr>
<td>Plgr Fall Vel in Liq, ft/sec</td>
<td>40.00 ft/min</td>
<td>12.19 m/min</td>
</tr>
<tr>
<td>Depth to Spring, ft</td>
<td>10000.00 ft</td>
<td>3048.00 m</td>
</tr>
<tr>
<td>Fraction of gas in Slug (~0.8)</td>
<td>0.8</td>
<td>0.80 Fraction</td>
</tr>
<tr>
<td>Fudge Factor: Adjust Shut-in Time (&gt;1)</td>
<td>1.10 F. Factor</td>
<td>1.10 F Factor</td>
</tr>
<tr>
<td>Desired Liquid Production, Rate</td>
<td>24.95 bpd</td>
<td>3.967 m³/day</td>
</tr>
<tr>
<td>Plunger Liquid Removal Effcy(per cycle)</td>
<td>0.90 dimless</td>
<td>0.90 dimless</td>
</tr>
<tr>
<td>Desired Plunger Rise Velocity</td>
<td>750 Ft/min</td>
<td>228.6 m/min</td>
</tr>
<tr>
<td>Produced Gas (Formation or Daily Rate)</td>
<td>21 Mscf/d</td>
<td>594.7 m³/day</td>
</tr>
<tr>
<td>Gas Leaks Past Plunger</td>
<td>21 Mscf/d</td>
<td>594.7 m³/day</td>
</tr>
</tbody>
</table>
Plunger Gas Requirement:
400 scf/bbl-1000' no packer
1000-2000 scf/bbl-1000' with packer
Following Graphs are for:

- **BPD** is the maximum rate for conditions
- Casing pressure is the operating pressure at end of Shut-in time Period
- Tubing pressure is the corresponding tubing pressure just before opening the well
- Liquid Slug Lifted Each time is related to (Casing – Tubing) Pressure
  - 1 BBL in 2.375 Tubing is 108 psi or 250 ft
  - 1 BBL in 2.875 Tubing is 74 psi or 171 ft
- Plunger fall velocity assumed to be 250 ft/min in gas and 40 ft/min in gaseous liquid
1 BBL in 2.375 Tubing is 108 psi or 250 ft
Well Depth has Minor Impact on Plunger Lift System Operation

For Well that is 4,000 to 10,000 Ft Deep ~ 750 Ft/Min Rise Velocity with 2.375" Tubing and 4.5" Casing

To lift 1 BBL/cycle to the Surface from 4000 Ft Requires 488 psi CP, to Lift 1 BBL from 10,000 Ft requires 505 Psi CP
Well Depth has Minor Impact on Plunger Lift System Operation

For well that is 4,000 to 10,000 Ft Deep ~ 750 Ft/Min Rise Velocity with 2.875" Tubing and 4.5" Casing

To lift 1 BBL/cycle to the Surface from 4000 Ft Requires 441 psi CP, to Lift 1 BBL from 10,000 Ft requires 453 psi CP
Performance: 2 3/8 – 4 ½ - 4000’

For Well that is 4000 Ft Deep ~ 750 Ft/Min Rise Velocity with 2.375” Tubing and 4.5” Casing

Tubing and Casing Psi at End of Shut-in

Maximum Liquid Production Rate - BPD

Line Pressure:
Performance:

2 3/8 – 4 1/2, 4000’

Line Pressure @ 400 Psi
- Producing BHP = 1100 Psi
- Static BHP = 2000 Psi
- Oil Rate = 1 BPD
- Water Rate = 44 BPD
- Gas Rate = 300 Mscf/D

Line Pressure @ 50 Psi
- Reduction in PBHP = 350 Psi
- Predicted Oil Rate = 1.3 BPD
- Predicted Gas Rate = 55.2 BPD
- Predicted Gas Rate = 376.2 Mscf/D
- Production Increase = 25.4%

Inflow Performance Relationship (Vogel) Curve

Line Pressure Lowered 400 to 50

Line Pressure Lowered 400 to 50

Producing Rate as a percentage of the maximum (100°Qf/Qmax)
Performance: 2 3/8 - 4 ½ - 6000’

For Well that is 6000 Ft Deep ~ 750 Ft/Min Rise Velocity
with 2.375” Tubing and 4.5” Casing
Performance: 2 3/8 – 4 ½ - 8000’
Performance: 2 3/8 – 4 ½ - 10,000’

For Well that is 10,000 Ft Deep ~ 750 Ft/Min Rise Velocity with 2.375" Tubing and 4.5" Casing

Maximum Liquid Production Rate - BPD

Tubing and Casing Psi at End of Shut-in

Line Pressure:
- 50
- 100
- 200
- 400

CP
TP
Required Casing Pressure is Reduced If Tubing size is Increased

For Well that is 8000 Ft Deep ~ 750 Ft/Min Rise Velocity with 2.375" & 2.875" Tubing and 4.5" Casing

Increased Tubing Size Reduces the Required Casing Pressure

250' = 108 psi
2.375"

171' = 74 psi
2.875"
Performance 2 7/8 – 4 ½ - 4000’

For Well that is 4000 Ft Deep ~ 750 Ft/Min Rise Velocity with 2.875" Tubing and 4.5" Casing
Performance: 2 7/8 – 4 ½ - 6000’

For Well that is 6000 Ft Deep ~ 750 Ft/Min Rise Velocity
with 2.875" Tubing and 4.5" Casing

Tubing and Casing Psi at End of Shut-in

Maximum Liquid Production Rate - BPD
Performance: 2 7/8 - 4 1/2 - 8000'

For Well that is 8000 Ft Deep ~ 750 Ft/Min Rise Velocity with 2.875" Tubing and 4.5" Casing
Performance: 2 7/8 - 4 ½ - 10,000'

For Well that is 10,000 Ft Deep ~ 750 Ft/Min Rise Velocity with 2.875" Tubing and 4.5" Casing
Plunger BPD with Depth, 2 3/8's, 4 1/2 casing
WHP: 100 psi, Fall Velocity 250 fpm gas, 40 fpm liquid
(CP is casing operating pressure available, psi)
Fast Falling Plunger will Increase Production

- .5 bbl slug
- 100 psi WHP
- 2 3/8’s

![Effect of Plunger Fall Velocity through Gas](image)
Larger Casing Reduces P Csg Requirement

Effects of Casing Size
6000', .5 bbl/cycle, 2 3/8's-2 7/8's 100 psi WHP

Required Casing BU

Pressure

Casing ID, Inches

4 4.5 5 5.5 6 6.5

0 100 200 300 400
Summary:

- Model used has been compared successfully to field data
- Improved model predicts casing pressure build-up for specified rise velocity with input of well conditions
- Use of result can show when plunger will begin to cease to perform requiring compression or other lift method/s
- Use of results can assist in optimization of on-going cycle performance
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