Top or Bottom?
Guidelines for Critical Velocity Calculations

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Changing Well Geometry

Velocity profile in gas well producing through 2-7/8-in tubing. EOT is 500-ft above perforations.
Question

• For a constant geometry (same tubing diameter), where does the maximum critical rate or velocity occur? At the top or bottom of the well?
Definitions & Assumptions

Geothermal Temperature Gradient

\[ g_T = 100 \left( \frac{T_e - T_{e0}}{D} \right) \]

where

- \( g_T \) = geothermal temperature gradient, °F/100 ft
- \( D \) = true vertical well depth, ft
- \( T_e \) = earth temperature at depth, °F
- \( T_{e0} \) = earth temperature at surface, °F

Assumption

Low gas flow rates associated with liquid loading result in temperature profile approximated by geothermal temperature gradient.
Simplified Unloading Equation

\[ v_t = C \frac{(\rho_L - 0.0031 \rho)^{0.25}}{(0.0031 \rho)^{0.5}} \]

For Turner’s method and water, \( C = 5.34 \)

with the following assumptions - \( \gamma_g = 0.6, \ T = 120 \degree F \) and \( Z = 0.9 \)

<table>
<thead>
<tr>
<th>Property</th>
<th>Water</th>
<th>Condensate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density, lbm/ft(^3)</td>
<td>67</td>
<td>45</td>
</tr>
<tr>
<td>Surface Tension, dynes/cm</td>
<td>60</td>
<td>20</td>
</tr>
</tbody>
</table>

\( \rho_L \) = liquid phase density, lbm/ft\(^3\)

\( \rho \) = pressure, psia

<table>
<thead>
<tr>
<th>Method</th>
<th>Water</th>
<th>Condensate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turner</td>
<td>5.34</td>
<td>4.02</td>
</tr>
</tbody>
</table>
Velocity – Gas Flow Rate Relationship

\[ q_g = 3056 \frac{P \nu A_p}{T_{abs} Z} \]

\[ v_t = \frac{q_g T_{abs} Z}{3056 P A_p} \]

where

- \( A_p \) = cross sectional area to flow, ft\(^2\)
- \( q_g \) = gas flow rate, MSCFD
- \( \nu \) = gas velocity, ft/sec
- \( P \) = pressure, psia
- \( T_{abs} \) = temperature, °R
- \( Z \) = gas compressibility factor
Turner Unloading Velocity

\[ v_t = 1.915 \left( \frac{\sigma}{\rho_g} \left( \rho_L - \rho_g \right) \right)^{0.25} \]

where

- \( \rho_g \) = gas phase density, lbm/ft³
- \( \rho_L \) = liquid phase density, lbm/ft³
- \( \sigma \) = interfacial tension, dynes/cm
- \( v_t \) = terminal velocity of liquid droplet, ft/sec
Gas Density Equation

\[ \rho_g = \frac{28.964 \gamma_g p}{10.73147 Z T_{abs}} \]

where

- \( \rho_g \) = gas density, lbm/ft\(^3\)
- \( \gamma_g \) = gas gravity (air = 1)
- \( p \) = pressure, psia
- \( T_{abs} \) = temperature, °R
- \( Z \) = gas compressibility factor
\( \gamma_w = 1.0 \)

\( \gamma_g = 0.65 \)
Effect of Temperature & Pressure on Critical Velocity & Rate

Effect of Temperature on Critical Velocity

- Temperature, °F vs. Critical Velocity, ft/sec
- Pressure levels: 100 psia, 500 psia, 1000 psia

Effect of Pressure on Critical Velocity

- Pressure, psia vs. Critical Velocity, ft/sec
- Temperature levels: 100 °F, 150 °F, 200 °F

Effect of Temperature on Critical Rate (2.441 Tbg)

- Temperature, °F vs. Critical Rate, MCFD
- Pressure levels: 100 psia, 500 psia, 1000 psia

Effect of Pressure on Critical Rate (2.441 Tbg)

- Pressure, psia vs. Critical Rate, MCFD
- Temperature levels: 100 °F, 150 °F, 200 °F
Effect of Pressure & Temperature

Effect of Pressure & Temperature on Velocity

- CV - 100 °F
- CV - 300 °F
- Simple Turner
- Vel - 100 °F
- Vel - 300 °F
Geothermal Gradient Summary

- Gulf Coast: 1.0-1.5 °F/100 Ft
- West Texas: 0.7-1.0 °F/100 Ft
- Rocky Mountain: 1.0-2.2 °F/100 Ft
- Netherlands: 1.7 °F/100 Ft
Effect of BHT on Pressure & Velocity

Change in BHT

- small effect on calculated BHP & critical velocity
- large effect on calculated velocity
Evaluation Point – Dry Gas

Critical Velocity Location
Effect of Analysis Technique

Wellhead Pressure, psia

Geothermal Gradient, Deg/100 Ft

Turner
Coleman

Use Downhole
Use Wellhead

Dtbg = 2.441 in
\( \gamma_g = 0.65 \)
Evaluation Point – Dry Gas

\[ \gamma_g = 0.65 \]

Critical Velocity Location
Effect of Tubing Size

Wellhead Pressure, psia

Geothermal Gradient, Deg/100 Ft

Use Wellhead

Use Downhole

\[ \text{1.610-in} \]
\[ \text{1.995-in} \]
\[ \text{2.441-in} \]
\[ \text{3.958-in} \]
Pressure Gradient Comparison

Test Data

\( Q_g = 1300 \text{ MCFD} \)

\( Q_w = 37 \text{ BWPD} \)

\( P_{wh} = 133 \text{ psia} \)

\( P_{bh} = 397 \text{ psia} \)

\( MD = 8357 \text{ ft} \)

\( TVD = 7127 \text{ ft} \)

\( D_{tbg} = 2.441 \text{ in} \)
Evaluation Point

Critical Velocity Location
Effect of Water Production

- **Dry Gas**
- **Gas-Water**

Wellhead Pressure, psia

Geothermal Gradient, Deg/100 Ft

**Use Downhole**

**Use Wellhead**

\[ D_{tg} = 2.441 \text{ in} \]

\[ \gamma_g = 0.65 \]
Incorrect Evaluation Point Errors – Dry Scenario

Surface vs Downhole Evaluation - 2.441 Tbg

Wellhead Pressure, psia vs Surface - Downhole Rate, MCFD

-100 0 100 200 300 400 500
10 100 1000 10000

Surface - Downhole Rate, MCFD

Wellhead Pressure, psia

-1.2 °F/100 Ft
-1.0 °F/100 Ft
-0.8 °F/100 Ft
-1.5 °F/100 Ft
-2.0 °F/100 Ft
Incorrect Evaluation Point Errors – Wet Scenario

Surface vs Downhole Evaluation - Water

Wellhead Pressure, psia

Surface - Downhole Rate, MCFD

-400 -300 -200 -100 0 100 200 300 400 500

10 100 1000 10000

-0.8 °F/100 Ft
-1.0 °F/100 Ft
-1.2 °F/100 Ft
-1.5 °F/100 Ft
-2.0 °F/100 Ft
Conclusions

• Effect of surface and downhole evaluation points have been examined with the following observations
  
• Minor impact on results
  – Ground temperature
  – Gas gravity
  – Water gravity
  – Well depth

• Moderate impact on results
  – Tubing diameter

• Major impact on results
  – Pressure environment
  – Temperature (geothermal gradient)
  – Actual presence of water
Conclusions

• For “dry” scenario, in general
  – WHP > 50 psia, use wellhead
  – WHP < 50 psia, use downhole

• For liquid producing scenario, in general
  – Use downhole for WHP < 1000 psia

• If DH conditions unavailable, use surface
  – Surface will get you in the “ball park”
  – Realize the magnitude of possible errors
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