Turner Critical Velocity Model Revisited

Rob Sutton
Turner Unloading Velocity
w/o 20% Adjustment

\[ v_t = 1.593 \frac{\left[ \sigma \left( \rho_L - \rho_g \right) \right]^{0.25}}{\rho_g^{0.5}} \]

where

- \( \rho_g \) = gas phase density, lbm/ft\(^3\)
- \( \rho_L \) = liquid phase density, lbm/ft\(^3\)
- \( \sigma \) = surface tension, dynes/cm
- \( v_t \) = terminal velocity of liquid droplet, ft/sec
Simplified Unloading Equations

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

<table>
<thead>
<tr>
<th>Method</th>
<th>Water (\rho_L)</th>
<th>Condensate (\rho_L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turner</td>
<td>5.321</td>
<td>4.043</td>
</tr>
<tr>
<td>Coleman</td>
<td>4.434</td>
<td>3.369</td>
</tr>
</tbody>
</table>

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

\(p\) = pressure, psia

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

<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>

From McInerney et al
Background on Turner’s Method

• 20% increase – Why?
  – Recommended Weber Number = 30, but matched better using 60 (Weber No. used to determine max droplet diameter)
  – Ratio = (60/30)^0.25=1.1892

• Water density
  – Turner proposed using a water gravity of 1.08 (67 lbm/ft^3) which he stated as the gravity of brine with a salinity of 28,000 ppm
    • Assumption is inconsistent
  – What about condensed water or temperature effect on density?

• Gas density & Surface tension
  – Varies with pressure and temperature
Brine Gravity and Salinity

Water Gravity - Salinity Relationship

- Water Specific Gravity vs. Salinity, ppm

Salinity, ppm:
- 0
- 50,000
- 100,000
- 150,000
- 200,000
- 250,000
- 300,000

Water Specific Gravity:
- 1.00
- 1.05
- 1.10
- 1.15
- 1.20
- 1.25
- 1.30
Gas Density

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

- \( \rho_g \) is the gas density in lbm/cuft
- \( \gamma_g \) is the specific gravity of the gas
- \( P \) is the pressure in psia
- \( Z \) is the compressibility factor
- \( T_{abs} \) is the absolute temperature in °F

 Gas Density = 0.0031*P is valid for Sgg=0.6, T=120 °F and P<1200 psia

\[ y = 0.00329x \]
\[ R^2 = 0.99896 \]

- 120 °F
- 60 °F
- 200 °F

\[ 60 \text{ °F} \rightarrow y=0.0040x \]
\[ 120 \text{ °F} \rightarrow y=0.0033x \]
\[ 150 \text{ °F} \rightarrow y=0.0030x \]
\[ 200 \text{ °F} \rightarrow y=0.0027x \]
\[ 250 \text{ °F} \rightarrow y=0.0024x \]
Water Density

Water Density

\[ y = -0.020x + 68.735 \]
\[ R^2 = 0.989 \]

\[ y = -0.019x + 63.785 \]
\[ R^2 = 0.968 \]
Condensate-Gas Surface Tension
(Graph Referenced by Turner)

from Katz et al
HBNGE pg 127
Condensate-Gas Surface Tension
(Appropriate Relationship – Live Reservoir Condensate)

The method of computing surface tension was applied to equilibrium mixtures of crude oil and natural gas. The results, along with data from Schwartz (4-81) and Jones (4-47), are given in Fig. 4-45 (4-18). Later, a comparison between the calculated and the measured surface tensions of a crude oil showed the measured value at 115°F and 2,700 psia to be 1.1 dynes/cm and the computed value to be 0.85 dyne/cm (4-50). In general, one can be fairly sure that a hydrocarbon liquid, condensate, or crude oil, saturated with natural gas in the reservoir at pressures of 3,000 psia or more, will have a surface tension of 2 dynes/cm or less. Table 4-17 gives an example

Live reservoir fluids from Katz et al HBNGE pg 129
Surface Tension

![Surface Tension Graph](image-url)
Turner Error
Simple PVT Compared to Rigorous PVT - Water

Error in Simple Turner - Water

Pressure, psia

% Error

60 °F
120 °F
150 °F
200 °F
250 °F

Feb. 23 - 26, 2009 2009 Gas Well Deliquification Workshop Denver, Colorado
Turner Error
Simple PVT Compared to Rigorous PVT – Gas Condensate

Error in Simple Turner - Condensate

-20 0 20 40 60 80 100 120 140 160

0 500 1000 1500 2000 2500 3000 3500

Pressure, psia

60 °F
120 °F
150 °F
200 °F
250 °F

% Error
Comparison of Turner & Coleman Data

Turner & Coleman Data
Wellhead Pressure

Test Number

Turner
Coleman

Wellhead Pressure, psia

0
1000
2000
3000
4000
5000
6000
7000
8000
9000
Comparison of Turner & Coleman Data

Turner & Coleman Data

Test Number
Comparison of Turner & Coleman Data

Turner & Coleman Data
Fluid Type

Test Number

Fluid Type, 1-Water, 2-Condensate

Turner

94 of 138 are GC

Coleman

6 of 56 are GC
Validate Calculations on Coleman’s Data

Use Turner without 20% adjustment
Validate Calculations on Coleman’s Data

Use Turner (all water) with 20% adjustment

Validate Coleman Data

- Data
- Reference Line

Calculated Critical Rate, MCFD vs. Literature Critical Rate, MCFD
Validate Calculations on Turner’s Data

Use Turner without 20% adjustment

Validate Turner Data

- Data
- Reference Line

Literature Critical Rate, MCFD vs. Calculated Critical Rate, MCFD
Intermediate Conclusions

• Coleman used water formulation only and included the “20%” adjustment.

• Turner specified water and condensate density and surface tension and used as recommended. Turner excluded the “20%” adjustment.

Note: 20% adjustment is actually 18.9%
Critical Velocity - Coleman Plot Recalculated

Critical Rate Test - Slugging - Water
Critical Rate Test - Slugging - Oil
Critical Rate Test - Oil
Turner Unloaded Water
Turner Unloaded Oil
Turner Loaded Water
Turner Loaded Oil
Turner Near Loaded Water
Turner Near Loaded Oil
Reference Line

Observations –
Similar character (some of Turner’s data was omitted)
Coleman data has 20% uplift, Turner data does not
Turner data dominated with gas-condensate tests (green data points)
Gas-condensate PVT assumptions could be improved
Critical Velocity Data

All data uses original Turner equation (20% increase not included)
Critical Velocity Data

Condensate data assumed to be affected by condensed water. All data modeled with water PVT (20% increase not included).
Effect of Critical Weber Number
For Proper Equation Adjustment

Adjustment = 0.64  (Weber No. = 5)
Adjustment = 1.28  (Weber No. = 80)
Equation Adjustment Factor
(Turner & Coleman Field Data)

Error in Liquid Loading Predictions

% Error in Predicted Liquid Loading

Equation Multiplier

Feb. 23 - 26, 2009 2009 Gas Well Deliquification Workshop Denver, Colorado
Conclusions

• Critical velocity fluid assumptions
  – Density and surface tension reviewed
    • Water system – probably okay for most situations
    • Gas-condensate system – probably okay for low pressure
    • Gas-condensate surface tension assumption (20 dynes/cm) not valid at higher pressure (> 300 psia)
    • Gas-condensate wells likely affected by condensed water
      – Use water PVT in critical velocity equations
  • Turner data dominated by gas-condensates
  • Comparisons in literature are inconsistent (use or don’t use “20%” adjustment to critical velocity)
  • “Correct” multiplier is actually a range (0.9-1.1)
  • Recommended multiplier is 1.1 to promote conservative results
Copyright

Rights to this presentation are owned by the company(ies) and/or author(s) listed on the title page. By submitting this presentation to the Gas Well Deliquification Workshop, they grant to the Workshop, the Artificial Lift Research and Development Council (ALRDC), and the Southwestern Petroleum Short Course (SWPSC), rights to:

– Display the presentation at the Workshop.
– Place it on the www.alrdc.com web site, with access to the site to be as directed by the Workshop Steering Committee.
– Place it on a CD for distribution and/or sale as directed by the Workshop Steering Committee.

Other uses of this presentation are prohibited without the expressed written permission of the company(ies) and/or author(s) who own it and the Workshop Steering Committee.
Disclaimer

The following disclaimer shall be included as the last page of a Technical Presentation or Continuing Education Course. A similar disclaimer is included on the front page of the Gas Well Deliquification Web Site.

The Artificial Lift Research and Development Council and its officers and trustees, and the Gas Well Deliquification Workshop Steering Committee members, and their supporting organizations and companies (here-in-after referred to as the Sponsoring Organizations), and the author(s) of this Technical Presentation or Continuing Education Training Course and their company(ies), provide this presentation and/or training material at the Gas Well Deliquification Workshop "as is" without any warranty of any kind, express or implied, as to the accuracy of the information or the products or services referred to by any presenter (in so far as such warranties may be excluded under any relevant law) and these members and their companies will not be liable for unlawful actions and any losses or damage that may result from use of any presentation as a consequence of any inaccuracies in, or any omission from, the information which therein may be contained.

The views, opinions, and conclusions expressed in these presentations and/or training materials are those of the author and not necessarily those of the Sponsoring Organizations. The author is solely responsible for the content of the materials.

The Sponsoring Organizations cannot and do not warrant the accuracy of these documents beyond the source documents, although we do make every attempt to work from authoritative sources. The Sponsoring Organizations provide these presentations and/or training materials as a service. The Sponsoring Organizations make no representations or warranties, express or implied, with respect to the presentations and/or training materials, or any part thereof, including any warrantees of title, non-infringement of copyright or patent rights of others, merchantability, or fitness or suitability for any purpose.