Pressure-Drop Predictions in Tubing in the Presence of Surfactants

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Introduction

- Foam flow is the most suitable artificial lift method for many tight gas wells.
- No correlation exists for pressure drop prediction in foam flow.
- Need a model to correctly predict the rate-pressure drop relationship under foam flow conditions.
Background

• Vendors are providing the most appropriate surfactants by conducting lab tests which include:
  – Foam stability (how quickly it dissipates)
  – Liquid carrying capacity
  – Type of surfactant
  – Concentration
**Background**

- The current methods to calculate the critical rate and pressure drop are based on Turner’s equation and dispersed droplet drift flux model (by assuming droplets with reduced liquid density)
- In reality, wet foam might have liquid continuous and gas discontinuous flow; therefore, Turner’s equation is not appropriate
Data Gathered

- **FIELD DATA:**
  - Numbers of Wells – 6
  - Numbers of Data Points – 570
  - Types of Surfactant – No information
  - Interfacial tension – no information.
  - Gas Flow Rate: 150-900 Mcf /D
  - Liquid Flow Rates: 10-130 BBL/D
Assumptions

• Only gas column is assumed to be present in casing to calculate bottom hole pressure.
• Surfactant concentration is above CMC.
• The same surfactants is used in all wells. The surface tension is constant for all the wells, and assumed equal to 2.0 Dynes/cm.
• Water will be the only produced liquid, also assumed incompressible.
Assumptions

- Surface tension is independent of temperature.
- The viscosity of the liquid, 0.95 CP for all wells. The mixture viscosity is calculated based on literature correlation.
- The temperature gradient along the well bore is 0.0143 °F/ft and surface temperature is 60 °F.
Conventional Approaches

- Ansari Mechanistic Model
  - Ansari flow pattern model forecast slug flow for most data points
  - Model pressure drop is compared with casing observed pressure drop

\[ \Delta P_{cal} = P_{Cal} - P_{wh} \]
\[ \Delta P_{obs} = P_{obs} - P_{wh} \]

- Result
  - Over prediction of pressure drop.
Conventional Approaches

![Graph showing data points and a line of best fit.](image-url)

- **ΔP<sub>Obs.</sub>** vs. **ΔP<sub>Cal.</sub>**

- The graph displays a scatter plot with observed and calculated pressure differences. The data points are distributed around the line of best fit, indicating a correlation between the observed and calculated values.
Conventional Approaches

• Homogeneous Model
  – No Slip hold up.
  – Viscosity based on mixture calculations
  – Better comparison than mechanistic model.

• Result
  – Indicates the possibility of slippage in flow.

\[ \lambda = \frac{V_{sg}}{V_{sl} + V_{sg}} \]
Conventional Approaches

Conventional Approaches

Homogeneous Model

\[ \Delta P_{\text{Obs.}} \] vs \[ \Delta P_{\text{Cal.}} \]

- Obs. Press. Drop.
- Cal. Press. Drop

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Conventional Approaches

• Slippage Model
  – Slippage velocity
    \[ V_s = V_g - C(V_m) \]
  – Modified bubble rise velocity by Zuber and Hench, 1962.

\[
V_s = 1.53 \left[ \frac{g \sigma_L (\rho_L - \rho_G)}{\rho_L^2} \right]^{1/4} (1 - \alpha)^n
\]

\[
1.53 \left[ \frac{g \sigma_L (\rho_L - \rho_G)}{\rho_L^2} \right]^{1/4} (1 - \alpha)^{0.5} = \frac{V_{sg}}{\alpha} - 1.2(V_m)
\]

– Hatschek (1911) Foam Viscosity Model/Deshpande (2000) friction factor model used

• Result
  – Over predicts the pressure drop.
Conventional Approaches

Conventional Slippage Model

![Graph showing Conventional Slippage Model]

- \( \Delta P_{Cal} \)
- \( \Delta P_{Obs} \)

- Obs, Press. Drop
- Cal, Press. Drop
Basic Drift Flux Model

• In foam flow, with fully plug flow velocity profile, Slip velocity is given by,

\[ V_s = V_g - (V_m) \]

  – Gas hold up is calculated by,

\[ 1.53 \left[ \frac{g \sigma_L (\rho_L - \rho_G)}{\rho_L^2} \right]^{1/4} = \frac{V_{sg}}{\alpha} - (V_m) \]

  – Zuber and Hench modification not used

• Result
  – Significant improvement but still trend is not properly predicted
  – Over prediction at lower pressure drop and lower prediction at higher pressure drop.
Basic Drift Flux Model

![Graph showing the relationship between observed pressure drop (ΔP_{obs}) and calculated pressure drop (ΔP_{cal})]
Modified Drift flux Model

• With similar surface tension
  – Shear effect of wall on fully plug velocity profile is incorporated.
  – The gas hold is calculated using,

\[
1.53 \left[ \frac{g \sigma_L (\rho_L - \rho_G)}{\rho_L^2} \right]^{1/4} = \frac{V_{sg}}{\alpha} - 1.03(V_m)
\]

• Result
  – Better prediction.
  – Prediction depends on individual well.
Modified Drift Flux Model

Wells With Similar Surface Tensions

\[ \Delta P_{\text{Cal.}} \]

\[ \Delta P_{\text{Obs.}} \]

- WELL 1
- WELL 2
- WELL 3
- WELL 4
- WELL 5
- WELL 6
Modified Drift Flux Model

- With different surface tension for each well representing different rise velocity
  - No surface tension details are available
- Result
  - Significant improvement in Prediction.
  - Defines significant effect of surface tension on bubble rise velocity and pressure drop prediction.

<table>
<thead>
<tr>
<th>Well</th>
<th>Surface Tension in Dyne/Cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>WELL 1</td>
<td>4</td>
</tr>
<tr>
<td>WELL 2</td>
<td>1</td>
</tr>
<tr>
<td>WELL 3</td>
<td>0.01</td>
</tr>
<tr>
<td>WELL 4</td>
<td>0.5</td>
</tr>
<tr>
<td>WELL 5</td>
<td>0.4</td>
</tr>
<tr>
<td>WELL 6</td>
<td>0.9</td>
</tr>
</tbody>
</table>
Modified Drift Flux Model

Wells With Different Surface Tensions

\[
\Delta P_{\text{Obs.}} \quad \Delta P_{\text{Cal.}}
\]

WELL 1  WELL 2  WELL 3  WELL 4  WELL 5  WELL 6
Summary

- Drift flux model predicts better pressure drop compared to conventional models.
- For frictional pressure drop calculation, non-Newtonian behavior of foam for viscosity calculation needs to be considered instead of simple mixing rule.
- Additional information about bubble rise velocity and mixture viscosity can significantly improve the model.
Recommendations

• In addition to pressure drop, knowledge about foam quality and retention of liquids needs to be collected. This information is typically available from vendors.

• Viscosity correlation for foam needs to be improved.

• Additional field data under more varied conditions need to be collected to expand the range of correlation.
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