Why foamers deliquify gas wells: bubbling towards increased production

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Liquid loading

Declining reservoir pressure
- Gas cannot drag liquid to surface
- Well becomes liquid loaded
Liquid loading

Declining reservoir pressure
- Gas cannot drag liquid to surface
- Well becomes liquid loaded
Liquid loading

Declining reservoir pressure
• Gas cannot drag liquid to surface
• Well becomes liquid loaded
Liquid loading

Declining reservoir pressure
• Gas cannot drag liquid to surface
• Well becomes liquid loaded
Liquid loading

(Bondurant and Hearn, 2008)
Liquid loading

Declining reservoir pressure
- Gas cannot drag liquid to surface
- Well becomes liquid loaded

From experience: Foam prevents liquid loading
Flow patterns

- Bubbly flow
- Slug flow
- Churn flow
- Annular flow

$U_{sg}$

van ‘t Westende (2008)
Flow patterns

van ‘t Westende (2008)
Flow patterns

van ’t Westende (2008)
Flow patterns

Co-current annular

Churn annular

van ’t Westende (2008)
Pressure drop curves

$u_{sl} = 1 \text{ cm/s}$

Single phase air flow
Air–water flow
Pressure drop curves

![Graph showing pressure drop curves with data points for single phase air flow and air-water flow. The minimum pressure drop (critical velocity) is indicated with a dashed line.]
Pressure drop curves

Churn annular

Co-current annular

Film reversal

Single phase air flow

Air–water flow

$u_{sl} = 1 \text{ cm/s}$
Pressure drop curves

Pressure drop due to friction

$u_{sl} = 1 \text{ cm/s}$
Pressure drop curves

Pressure drop due to hydrostatic head

$u_{sl} = 1 \text{ cm/s}$

- Churn annular
- Co-current annular
- Single phase air flow
- Air–water flow

Graph showing pressure drop (Pa/m) vs. $u_{sg}$ (m/s) with data points for different flow conditions.
Pressure drop curves

Expectation: Foam will shift minimum

$u_{sl} = 1 \text{ cm/s}$

- Single phase air flow
- Air–water flow
Approach

- Measure pressure drop with and without foam
- Visual observation and initial understanding
  - How does the flow change by adding surfactants?
  - Why does foam change the pressure drop curve?
12 m, 5 cm ID flow-loop

Air-water
Atmospheric pressure

Water inlet
12 m, 5 cm ID flow-loop
12 m, 5 cm ID flow-loop
Measurement techniques: high speed movies

Movies captured at 1000 fps
Movies played at 10 fps
Measurement techniques: high speed movies

Movies captured at 1000 fps

1000 W Lamps

Transparent sheet

Camera (1000 fps)
Measurement techniques: high speed movies

Movies captured at 1000 fps
Movies played at 10 fps

1000 W Lamps
Camera (1000 fps)
Transparent sheet

Water to tank
Air

8 m
10 m
Movies of the inside of the pipe

Camera (1000 fps)
Hold-up valves

Water outlet

Water inlet

~0.5m

~9m

~1.5m
Hold-up valves

Water outlet

Water inlet

~0.5 m

~9 m

~1.5 m

0 ms
Water injection

\[ u_{sg} = 21 \text{ m/s}, \quad u_{sl} = 1 \text{ cm/s} \]
Pressure drop curve revisited (water, $u_{sl} = 1\, \text{cm/s}$)
Pressure drop curve revisited (water, $u_{sl} = 1\text{ cm/s}$)

- Loading point
- Churning
- Reversal onset
- Critical velocity

Flow visualization

$u_{sl} = 1\text{ cm/s}$

$dP/dx$ (Pa/m) vs. $u_{sg}$ (m/s)
Movie: water $u_{sl} = 1 \text{ cm/s}$

<table>
<thead>
<tr>
<th>Loading point</th>
<th>Churning</th>
<th>Reversal onset</th>
<th>Critical velocity</th>
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<tbody>
<tr>
<td>$u_{sg} = 6.4 \text{ m/s}$</td>
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Introducing foam

• Foamer: Trifoam 820 Block (Oilchem GmbH, Dessau-Roßlau, Germany)

• Coming movie:
• \( U_{sl} = 1 \text{ cm/s} \)
• \( U_{sg} = 10.7 \text{ m/s} \) (Churning)
Introducing foam

• Foamer: Trifoam 820 Block (Oilchem GmbH, Dessau-Roßlau, Germany)

• Usl = 1 cm/s

• Usg = 10.7 m/s (Churning)
Pressure drop when adding foamer

\[ u_{sl} = 1 \text{ cm/s} \]
Pressure drop when adding foamer

\[ u_{\text{sl}} = 1 \text{ cm/s} \]
Pressure drop when adding foamer

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Pressure drop when adding foamer

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Pressure drop when adding foamer

\[ u_{sl} = 1 \text{ cm/s} \]
Pressure drop when adding foamer

\( u_{sl} = 1 \text{ cm/s} \)

\( C \) (ppm)  \( u_{sg} \) (m/s)
Pressure drop when adding foamer

\[ u_{sl} = 1 \text{ cm/s} \]

\[ C \text{ (ppm)} \]

\[ u_{sg} \text{ (m/s)} \]
Pressure drop when adding foamer

\[ u_{sl} = 1 \text{ cm/s} \]
Pressure drop when adding foamer

$u_{sl} = 1 \text{ cm/s}$
Time dependent behavior

Pressure drop (Pa/m) vs. C (ppm)

$U_{sl} = 1 \text{ cm/s}$

$U_{sg} = 10 \text{ m/s}$

Churning
Time dependent behavior

$U_{sl} = 1 \, \text{cm/s}$  \hspace{1cm} \textbf{Churning}  \hspace{1cm} U_{sg} = 10 \, \text{m/s}$
Time dependent behavior

0 ppm

Pressure drop (Pa/m)

time (seconds)

$U_{sl} = 1 \text{ cm/s}$  Churning
$U_{sg} = 10 \text{ m/s}$
Time dependent behavior

U_{sl} = 1 \text{ cm/s} \quad \text{Churning} \\
U_{sg} = 10 \text{ m/s}

0 ppm \quad 200 ppm

Pressure drop (Pa/m)

time (seconds)
Time dependent behavior

$U_{sl} = 1 \text{ cm/s}$  
$U_{sg} = 10 \text{ m/s}$

Churning
Time dependent behavior

$U_{sl} = 1 \text{ cm/s}$
$U_{sg} = 10 \text{ m/s}$

Churning
Time dependent behavior

$U_{sl} = 1 \text{ cm/s}$  
$U_{sg} = 10 \text{ m/s}$

Churning
Time dependent behavior

U_{sl} = 1 \text{ cm/s} \quad \textbf{Churning}
U_{sg} = 10 \text{ m/s}
Measurements at 1000 ppm

$u_{sl} = 1 \text{ cm/s}$
Measurements at 1000 ppm

C=1000 ppm
1000 ppm contour: comparison

Foam

Water
1000 ppm contour: comparison
Flow visualization (constant $u_{sl}$)

$C = 1000$ ppm
Flow visualization (constant $u_{sg}$)

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Flow visualization (constant $u_{sl}$)

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Movies of the inside of the pipe

Camera (1000 fps)

Air

Wake
Flow visualization (constant $u_{sl}$)

- Flooding point
  - $u_{sg} = 6.4 \text{ m/s}$
  - $u_{sg} = 16.1 \text{ m/s}$

- Churning
  - $u_{sg} = 10.7 \text{ m/s}$
  - $u_{sg} = 21.5 \text{ m/s}$

Reversal onset

Critical velocity

$g$
Flow visualization (constant $u_{sl}$)

Flooding point

Churning

Reversal onset

Critical velocity

g

$u_{sg} = 6.4 \text{ m/s}$

$u_{sg} = 16.1 \text{ m/s}$

$u_{sg} = 10.7 \text{ m/s}$

$u_{sg} = 21.5 \text{ m/s}$

1 cm
Flow visualization (constant $u_{sg}$)

1000 ppm

$u_{sg}$ (m/s)

$u_{sl}$ (m/s)

$dP/dx$ (Pa/m)
$u_{sl} = 2 \text{ mm/s}$  
$u_{sl} = 10 \text{ mm/s}$  
$u_{sl} = 20 \text{ mm/s}$  
$u_{sl} = 40 \text{ mm/s}$
Pressure drop $u_{sg} = 10 \text{ m/s}$
Hold-up valves

Water outlet

Water inlet

~0.5m

~9m

~1.5m
Effect of surfactants on hold up

\[ u_{sl} = 1 \text{ cm/s}; 1000 \text{ ppm} \]
Conclusion

- Minimum of pressure drop curve becomes a plateau when adding foamer
  - Critical velocity no longer well defined
  - Works best for low liquid velocities

- Foam suppresses churning
  - Lower hold-up
  - Lower pressure drop
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