High Speed Video Observations for Plunger Lift Upstroke

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Overview

- Plunger lift is widely used for gas well deliquification
- Several modeling studies has been proposed
  - Foss and Gaul (1965)
  - Lea (1982)
  - Rosina (1983)
  - Gasbarri and Wiggins (1996)
  - Maggard et al. (2000)
  - Zhao et al. (2017)
Some other studies focused on experimental evaluation

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Facility Height</th>
<th>Facility Dimension</th>
<th>Test Fluids</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beason et al.</td>
<td>1958</td>
<td>From 3050-ft</td>
<td>2-in Plunger</td>
<td>Oil</td>
<td>Empirical Correlation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>To 11727-ft</td>
<td>2.5-in Plunger</td>
<td>Gas</td>
<td></td>
</tr>
<tr>
<td>Rosina</td>
<td>1983</td>
<td>60-ft</td>
<td>1-in Tubing</td>
<td>Air</td>
<td>Plunger Velocity</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3-in Casing</td>
<td>Water</td>
<td>Liquid Fall Back</td>
</tr>
<tr>
<td>Hernandez et al.</td>
<td>1993</td>
<td>65-ft</td>
<td>2 3/8-in Tubing</td>
<td>Air</td>
<td>Plunger Velocity</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>No Casing</td>
<td>Water</td>
<td>Liquid Fall Back</td>
</tr>
<tr>
<td>Baruzzi</td>
<td>1995</td>
<td>4.3-ft</td>
<td>1.8-in Tubing</td>
<td>Oil</td>
<td>Plunger Velocity</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.9-in Casing</td>
<td>Gas</td>
<td>Production Rate</td>
</tr>
<tr>
<td>Zhao et al.</td>
<td>2017</td>
<td>33-ft</td>
<td>2.44-in Tubing</td>
<td>Air</td>
<td>Optimum Diameter</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>No Casing</td>
<td>Water</td>
<td>Plunger Velocity</td>
</tr>
</tbody>
</table>
In general

- Assumption of constant plunger rise velocity (Foss and Gaul 1965)
- Most of the studies neglected gas slippage
- No study emphasized different plunger designs

This study is focused on plunger fluid interaction using high speed video recording

- Different type of plungers are considered
Facility

- Independent variables
  - Liquid load
  - Casing pressure

- Measurements
  - Produced liquid
  - Low frequency
    - Liquid load
    - Pressure readings
    - Return liquid level
  - High frequency
    - Sensor readings
# Plungers

<table>
<thead>
<tr>
<th></th>
<th>Spiral</th>
<th>Dual Pad</th>
<th>Brush</th>
<th>Venturi Viper</th>
<th>Bar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Used</td>
<td></td>
<td>#1</td>
<td>#1</td>
<td>V6</td>
<td>Stock</td>
</tr>
<tr>
<td>New</td>
<td></td>
<td>#2</td>
<td>#2</td>
<td>V10</td>
<td>Sphere</td>
</tr>
</tbody>
</table>

- **Spiral**
- **Dual Pad**
- **Brush**
- **Venturi Viper**
- **Bar**

**Used**
- V6
- V10

**New**
- Stock
- Sphere
**Experimental Matrix**

- 11 plungers plus base case (no plunger)
- 7 repetitions (76 conditions, 532 experiments)

<table>
<thead>
<tr>
<th>$L_s$ [ft.]/$P_c$ [psi]</th>
<th>4-ft</th>
<th>6-ft</th>
<th>8-ft</th>
<th>Plungers</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 psi</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>11</td>
</tr>
<tr>
<td>12 psi</td>
<td>✓</td>
<td>✓</td>
<td>✗</td>
<td>11</td>
</tr>
<tr>
<td>7 psi</td>
<td>✓</td>
<td>✗</td>
<td>✓</td>
<td>7</td>
</tr>
</tbody>
</table>
Experimental Procedure
Plunger Velocities ($p_{Casing} = 15$ psig)

**Bar Stock 1.90**

- $W = 7.3$ lb
- $OD = 1.90$ in.
- $L = 14$ in.

**Sphere**

- $W = 1$ lb
- $OD = 1.90$ in.
- $L = 1.90$ in.
Plunger Velocities \( \left( p_{\text{Casing}} = 15 \text{ psig} \right) \)...

Bar Stock 1.90

\[ W = 7.3 \text{ lb} \]
\[ OD = 1.90 \text{ in.} \]
\[ L = 14 \text{ in.} \]

Bar Stock 1.85

\[ W = 7.3 \text{ lb} \]
\[ OD = 1.85 \text{ in.} \]
\[ L = 14 \text{ in.} \]
Plunger Velocities (6 ft Load)

Casing Pressure = 15 psi

Casing Pressure = 12 psi

Plunger Velocity (fpm)

Section #1 Section #2 Section #3 Section #4 Section #5 Section #6

- Sphere
- Brush #2
- Bar Stock 1.85
- V6
- Dual Pad #1
- New Spiral

- Bar Stock 1.90
- Brush #1
- Used Spiral
- Dual Pad #2
- V10

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Plunger Fluid Behavior

- Slug front
- Liquid slug region
- Taylor bubble region
- Plunger front
- Plunger region
- Gas blowing trough
- Film region
- Droplets
Slug Body Characteristics

4-ft  
6-ft  
8-ft
Taylor Bubble Characteristics

4-ft  6-ft  8-ft
Liquid Slug Characteristics

\[ \frac{\alpha}{\beta} \text{ Pixels} = \frac{\text{Pipe Diameter}}{\text{Distance}} \]

\[ \text{Velocity} = \frac{\text{Distance}}{\text{Frames}/2500\text{FPS}} \]
Liquid Slug Characteristics…

![Graph showing velocity comparison for different devices](image-url)
Film Left Behind

No plunger

Bar Stock plunger
Main source of liquid fall back
For the investigated plungers
  - 10%-15%

**Clearance**

\[
\text{Clearance} = 1 - \frac{\pi \cdot D_{\text{Plunger}}^2}{\pi \cdot ID_{\text{Tubing}}^2}
\]
Clearance Effect

Bar Stock 1.85

Bar Stock 1.90
Droplets

- During after flow, gas flow carries liquid droplets moving upward
- These droplets are the liquid below the plunger/bumper spring
- Negligible for the project
- Example showing
  - 1.90-in diameter rod plunger
  - Casing pressure = 15 psi
  - Liquid load = 8-ft
## Final Observations

<table>
<thead>
<tr>
<th>Plunger Style</th>
<th>Plunger Velocity</th>
<th>High Speed Video Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bar Stock 1.90</td>
<td>Higher load results in lower velocity; plunger slows down after reaching maximum velocity; the higher the load, the earlier plungers start to slow down</td>
<td>Gas move faster than plunger in the annulus and sweep liquid film upward</td>
</tr>
<tr>
<td>Bar Stock 1.85</td>
<td>Slightly faster in small load condition; Slightly slower in high load condition</td>
<td>Similar gas behavior; Thicker film and more droplets left behind</td>
</tr>
<tr>
<td>Used Spiral</td>
<td>Slower in all conditions</td>
<td>Similar gas behavior; Holes on body emits gas</td>
</tr>
<tr>
<td>New Spiral</td>
<td>Slower in all conditions; Slower than Used Spiral in all conditions</td>
<td>Similar gas behavior; Holes on body emits gas</td>
</tr>
<tr>
<td>Dual Pad #1</td>
<td>Slower in all conditions</td>
<td>Similar gas behavior; Pads sweeping the pipe wall</td>
</tr>
<tr>
<td>Dual Pad #2</td>
<td>Slower in all conditions; Slower than Dual Pad #1 in all conditions</td>
<td>Similar gas behavior; Pads sweeping the pipe wall</td>
</tr>
<tr>
<td>Brush #1</td>
<td>Higher in all conditions</td>
<td>Similar gas behavior</td>
</tr>
<tr>
<td>Brush #2</td>
<td>Faster when casing pressure is 15 psi and 12 psi; slower when casing pressure is 7 psi</td>
<td>Similar gas behavior; Gas bubbles trapped in the fishneck</td>
</tr>
<tr>
<td>Venturi V6</td>
<td>Slower when casing pressure is 15 psi and 12 psi; faster when casing pressure is 7 psi</td>
<td>Similar gas behavior</td>
</tr>
<tr>
<td>Venturi V10</td>
<td>Slowest among all plungers in all conditions</td>
<td>Similar gas behavior</td>
</tr>
<tr>
<td>Sphere</td>
<td>Fastest among all plungers in all conditions</td>
<td>Similar gas behavior</td>
</tr>
</tbody>
</table>
## Final Observations

<table>
<thead>
<tr>
<th>Plunger Style</th>
<th>Taylor Bubble Velocity</th>
<th>Differential Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bar Stock 1.90</td>
<td>Aroung 1550 fpm</td>
<td>Aroung 400 fpm</td>
</tr>
<tr>
<td>Bar Stock 1.85</td>
<td>Higher</td>
<td>Higher</td>
</tr>
<tr>
<td>Used Spiral</td>
<td>Similar</td>
<td>Similar</td>
</tr>
<tr>
<td>New Spiral</td>
<td>Similar</td>
<td>Similar</td>
</tr>
<tr>
<td>Dual Pad #1</td>
<td>Similar</td>
<td>Similar</td>
</tr>
<tr>
<td>Dual Pad #2</td>
<td>Similar</td>
<td>Similar</td>
</tr>
<tr>
<td>Brush #1</td>
<td>Similar</td>
<td>Similar</td>
</tr>
<tr>
<td>Brush #2</td>
<td>Similar</td>
<td>Similar</td>
</tr>
<tr>
<td>Venturi V6</td>
<td>Significantly higher</td>
<td>Significantly higher</td>
</tr>
<tr>
<td>Venturi V10</td>
<td>Even higher than V6</td>
<td>Even higher than V7</td>
</tr>
<tr>
<td>Sphere</td>
<td>Higher</td>
<td>Similar</td>
</tr>
</tbody>
</table>
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