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# Understanding Liquid Loading Will Improve Well Performance

**Rob Sutton**


Society of Petroleum Engineers
Distinguished Lecturer Program
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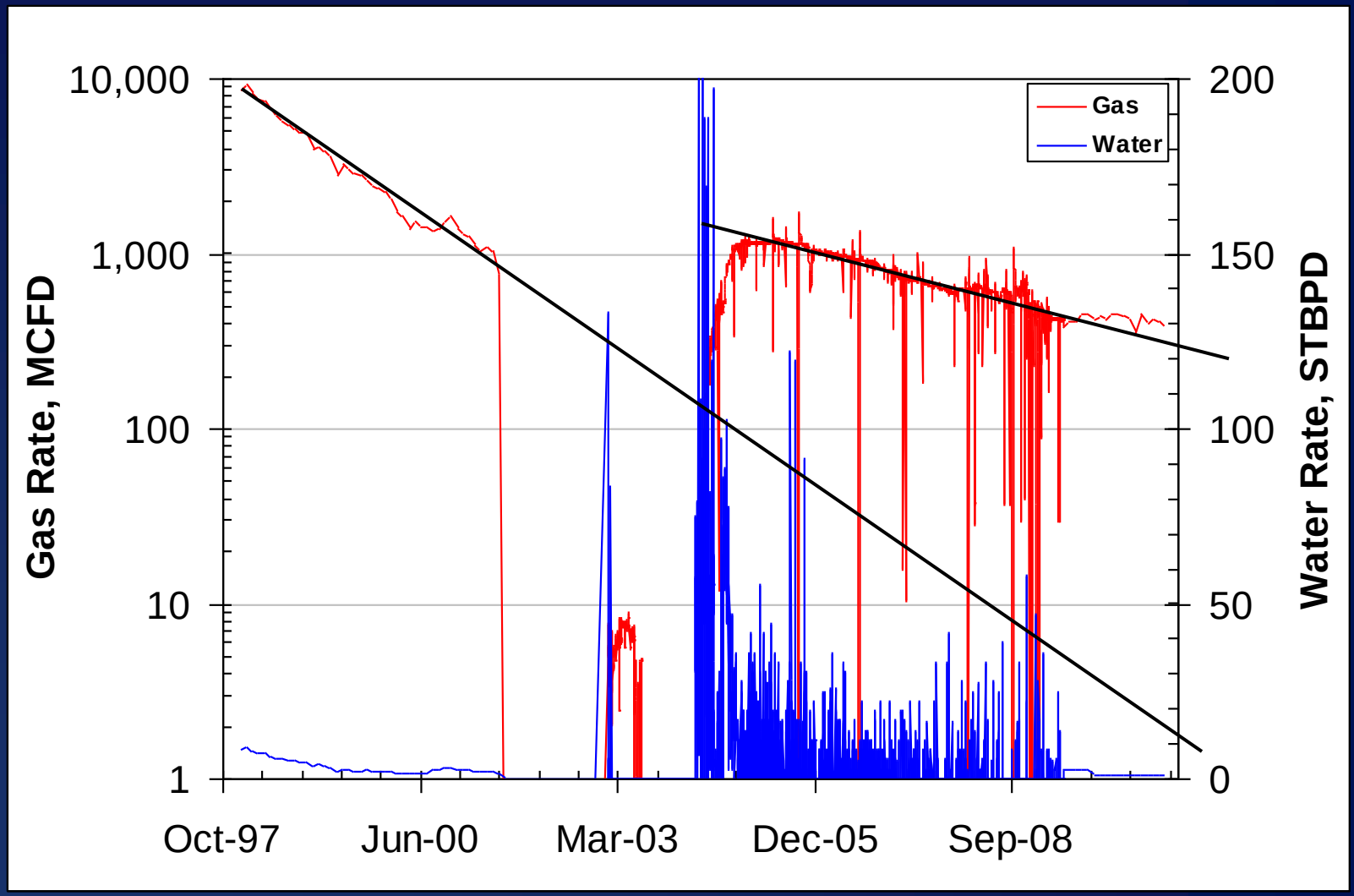
# Example of Successful Deliquification Program

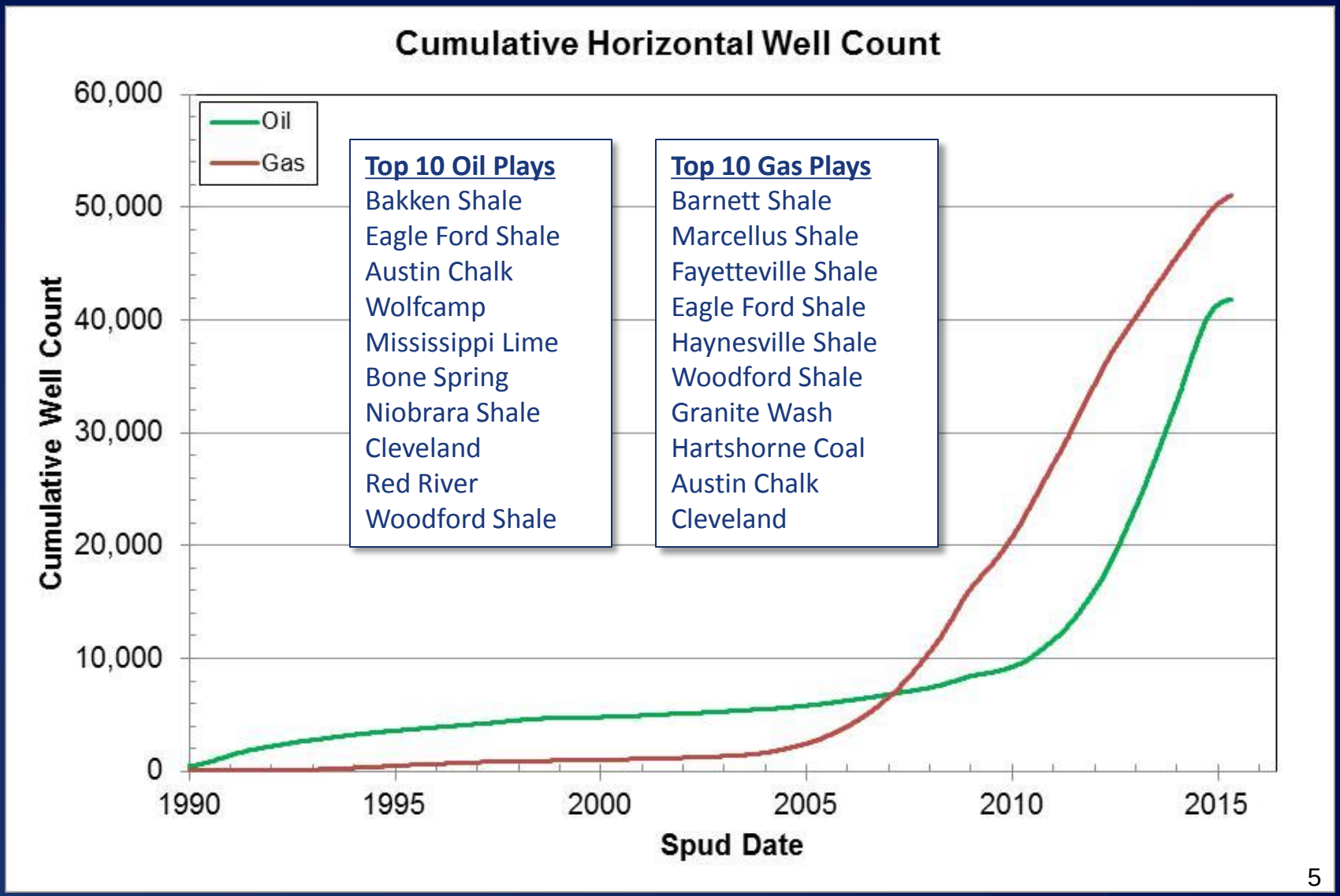


# Purpose

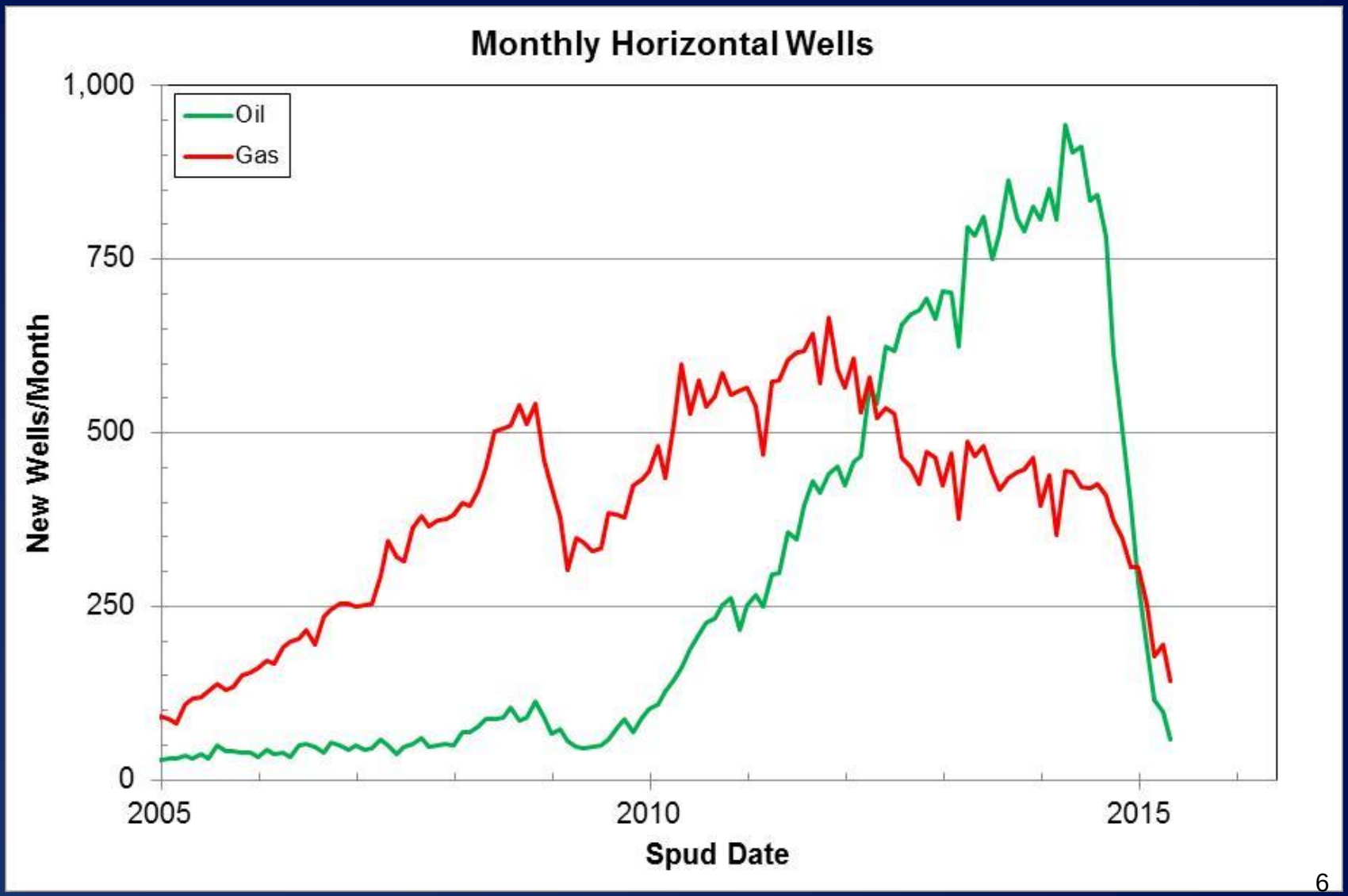
**Address the following question:**

Can complex well geometries affect liquid loading characteristics and well performance?

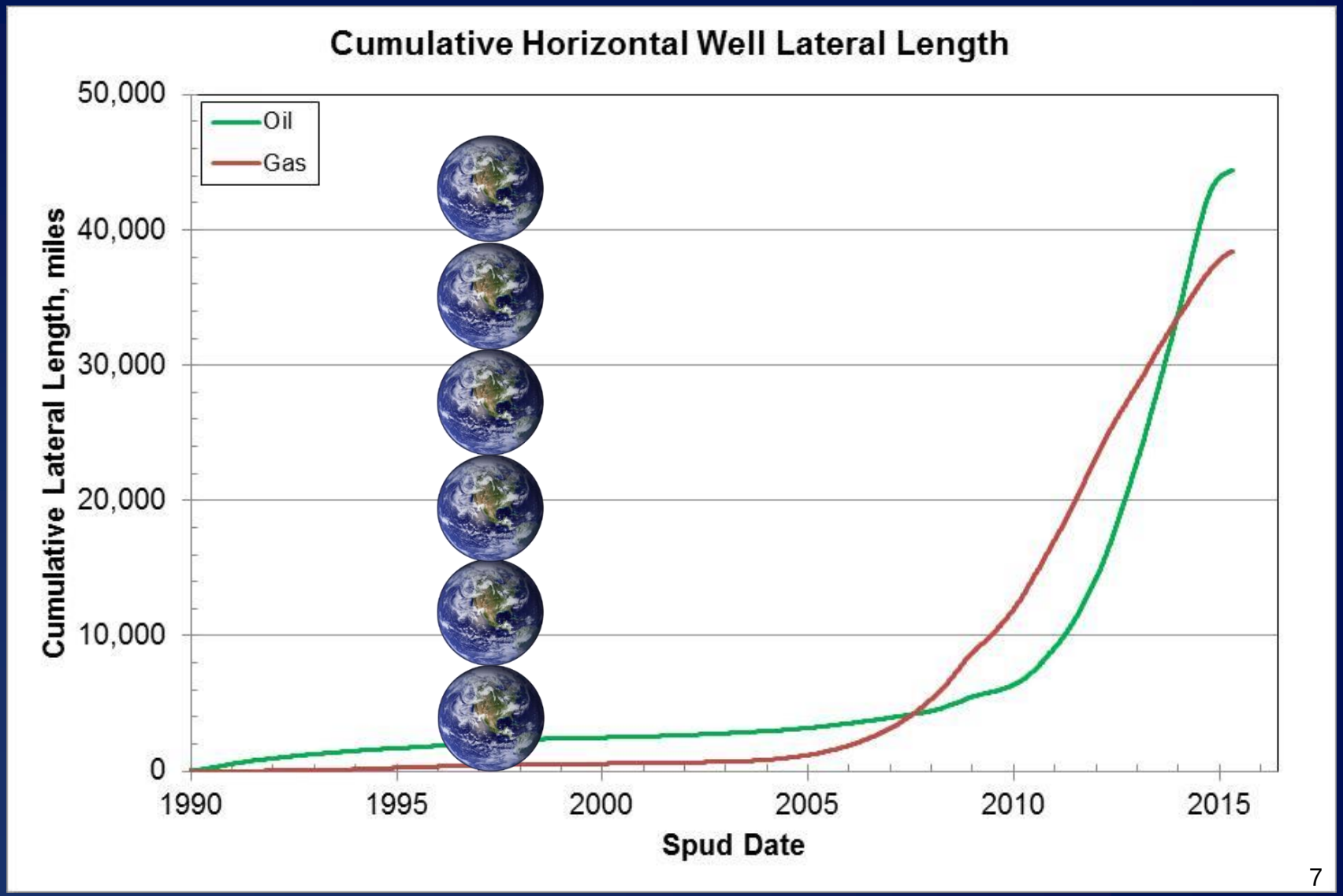
# How Relevant are Gas Wells?



# How Relevant are Gas Wells?



# Lateral Length



# Terminology

- Critical velocity
- Critical rate
- Static liquid column
- Terrain slugging
- Severe slugging
- Vertical Flow Performance
  - VFP Curves
  - Nodal Analysis

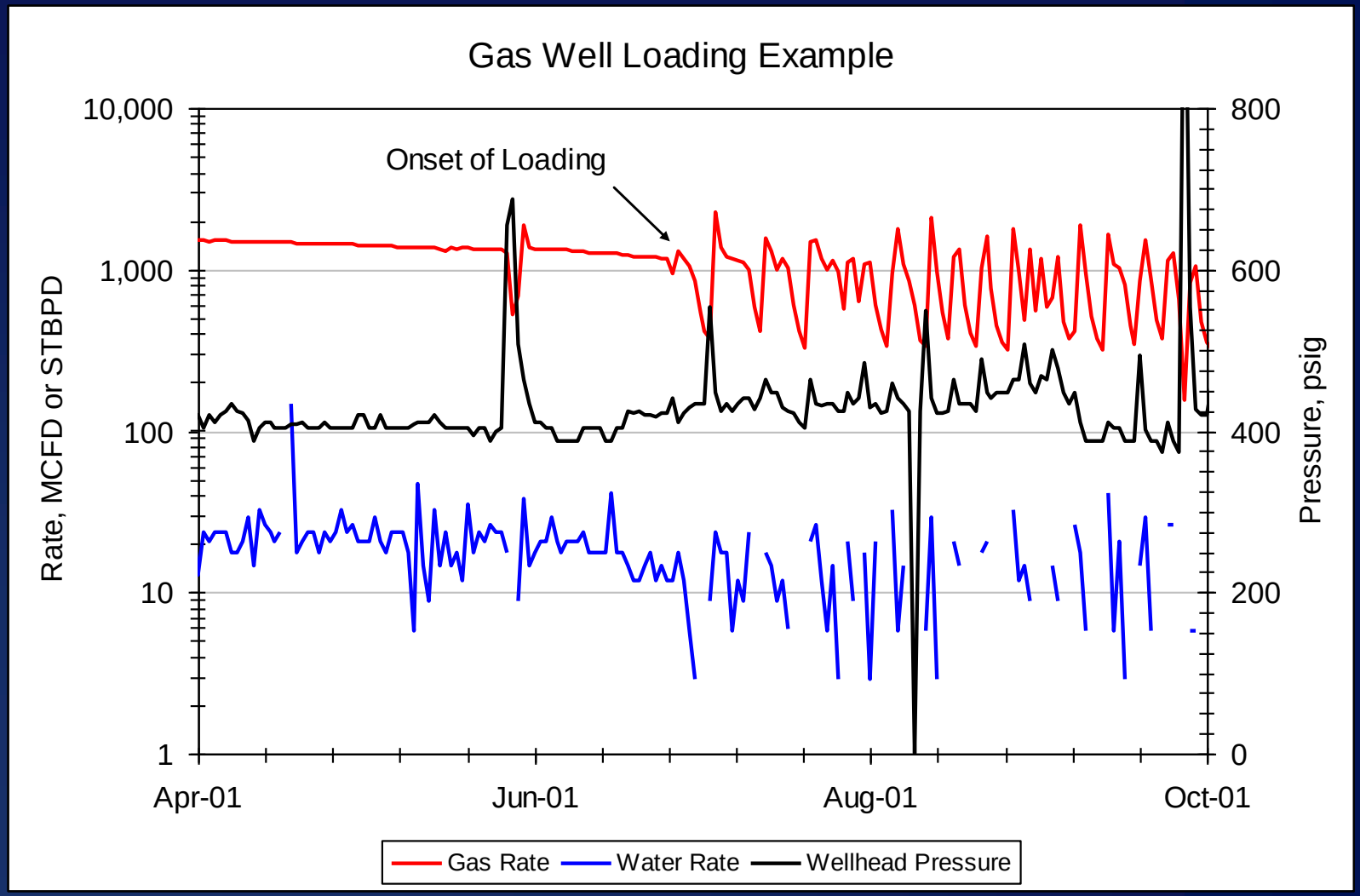
# Analysis Techniques

- Vertical flow performance curves
- Critical velocity
- Production graphs
  - Rate vs Time
  - Pressure vs Time
- Flowing pressure surveys
- Acoustic survey

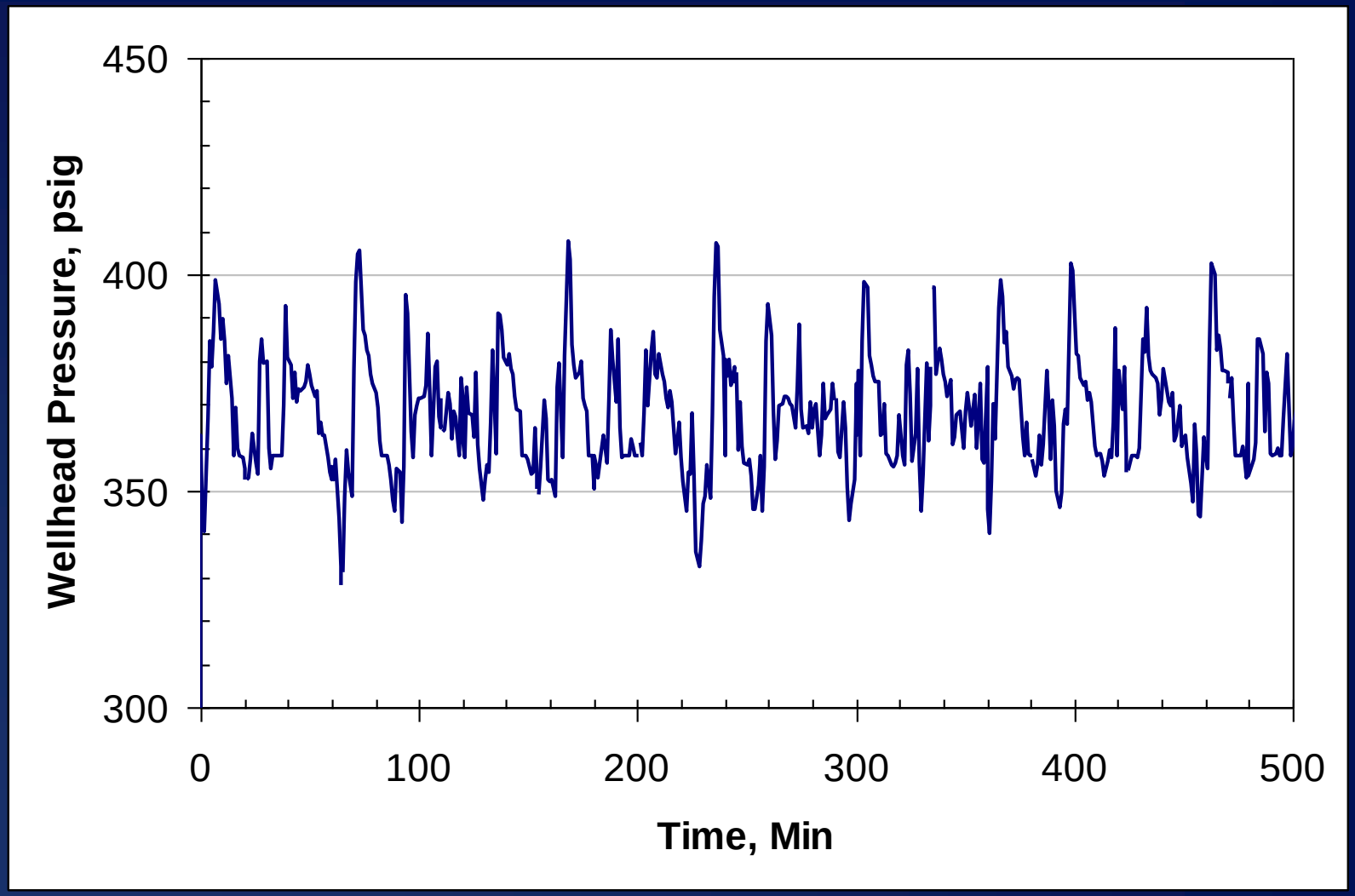
# Complications

- Tubing set high above perforations
- Long completion intervals
- Complex well geometries
- Problem recognition

# Production Data

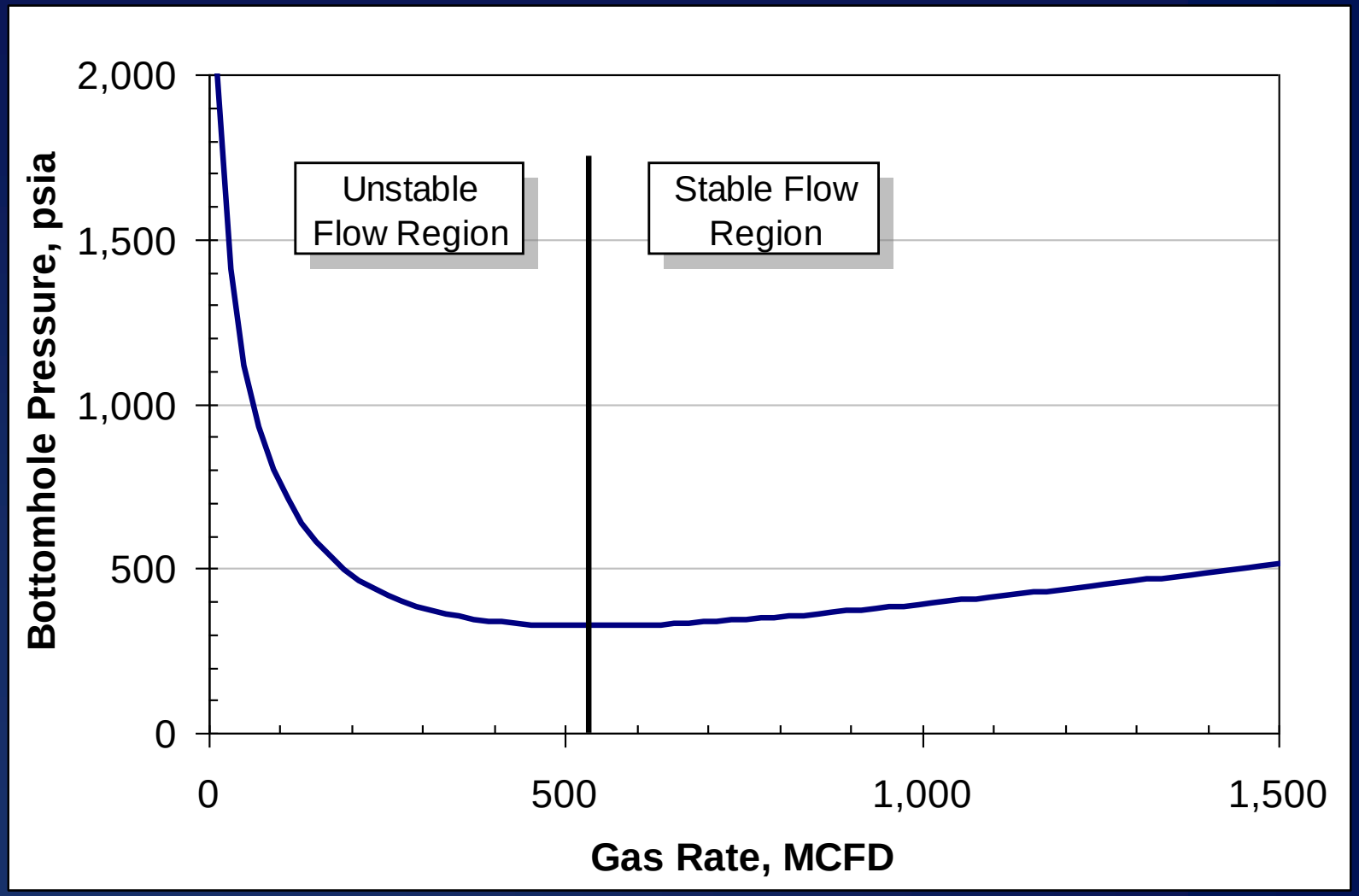


# Pressure Data

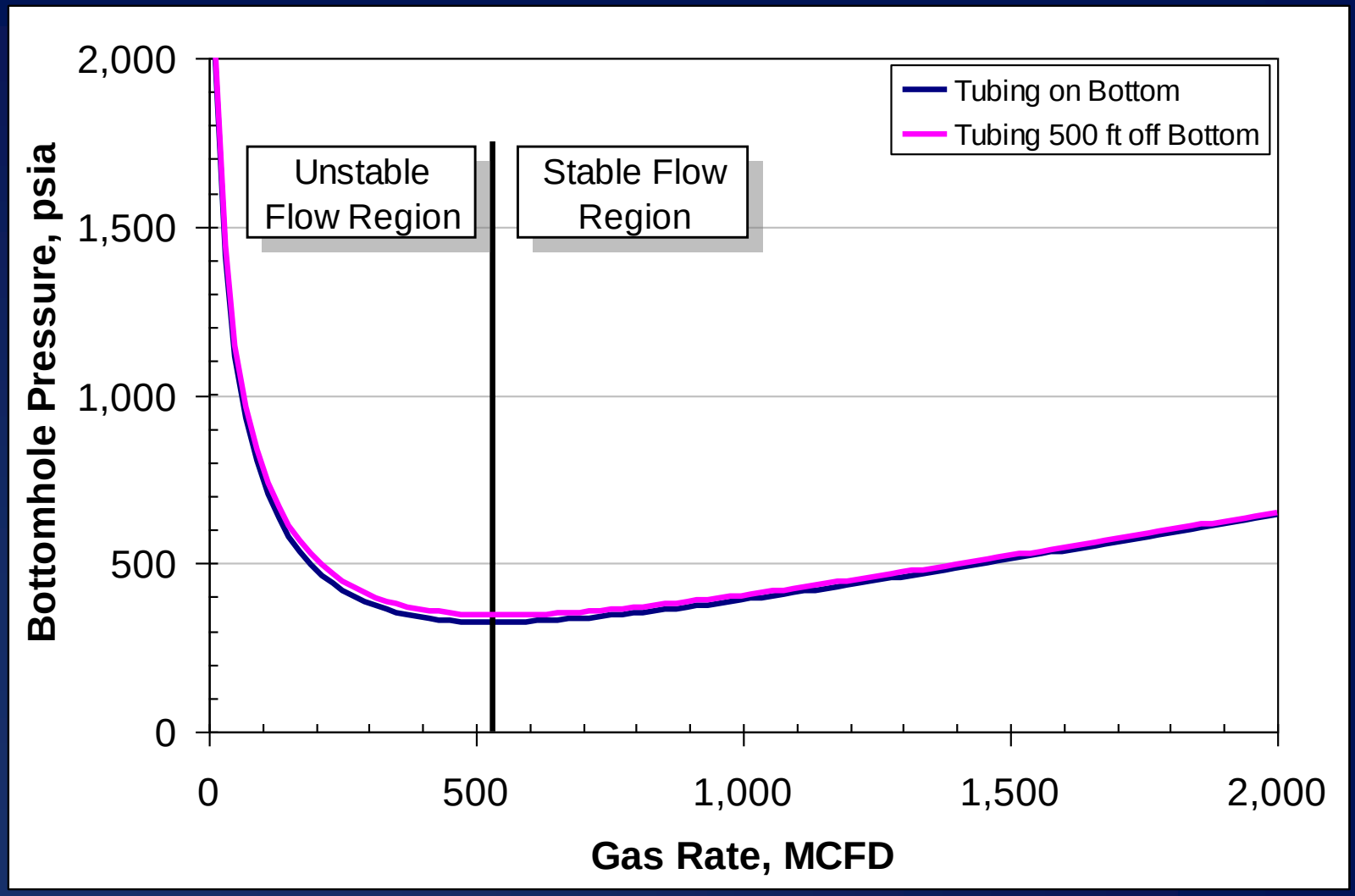


# Critical Rate

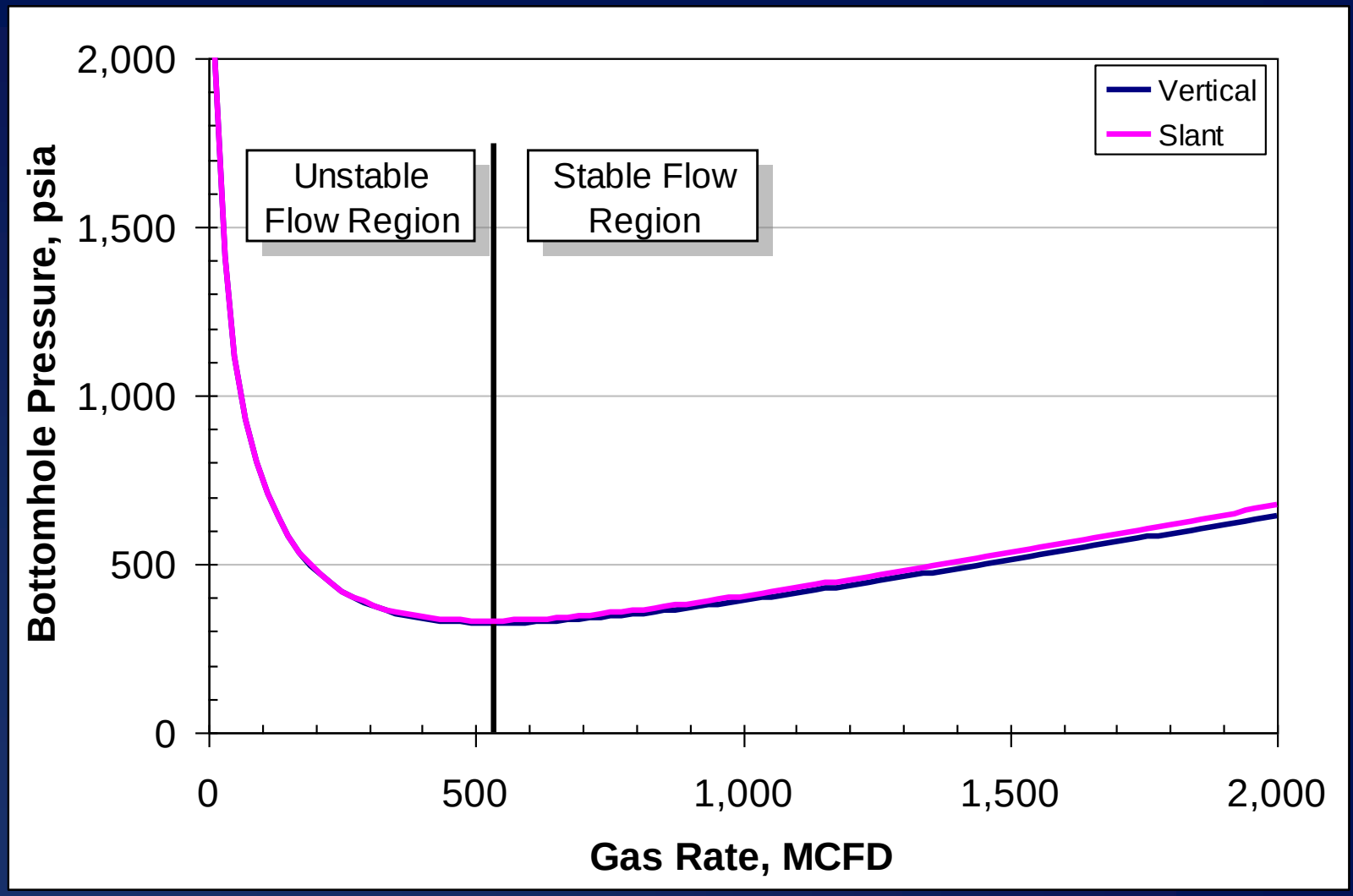
## Vertical Flow Performance



# Tubing on Bottom vs Tubing Set High



# Vertical vs Slant Well Geometry



# Unloading Velocity

- Equation derived for vertical well
- Developed from terminal fall velocity
  - Liquid density
  - Gas density
  - Largest liquid droplet
- Frequently termed “critical velocity”

# Turner Unloading Velocity

$$v_c = 1.5934\left[\frac{\sigma\left(\rho_l - \rho_g\right)}{\rho_g^2}\right]^{0.25}$$

Without ±20% adjustment
Coleman Equation

where

$\rho_g$ = gas phase density, lbm/ft$^3$

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

$\sigma$ = surface tension, dynes/cm

$v_c$ = critical velocity of liquid droplet, ft/sec

# Turner Unloading Velocity

$$v_c = 1.5934 \left[\frac{N_{we}}{30}\right]^{0.25} \left[\frac{\sigma(\rho_l - \rho_g)}{\rho_g^2}\right]^{0.25} \frac{[\sin(1.7(90-\theta))]^{0.38}}{0.740767}$$

Turner Adjustment

Belfroid et al SPE 115567 Angle Correction

where

$\rho_g$ = gas phase density, lbm/ft$^3$

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

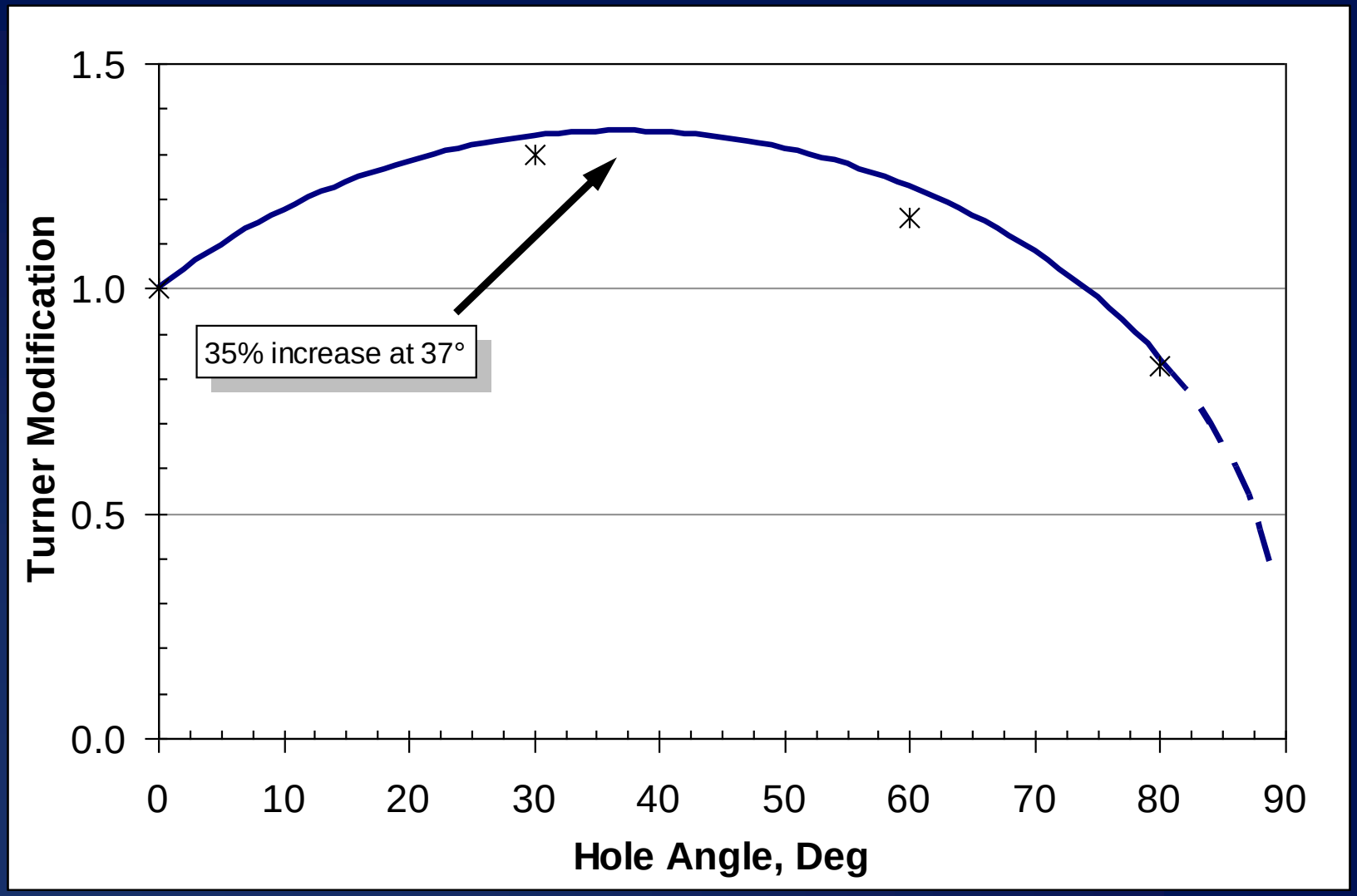
$\sigma$ = surface tension, dynes/cm

$N_{we}$ = Weber Number (use 60 for original Turner)

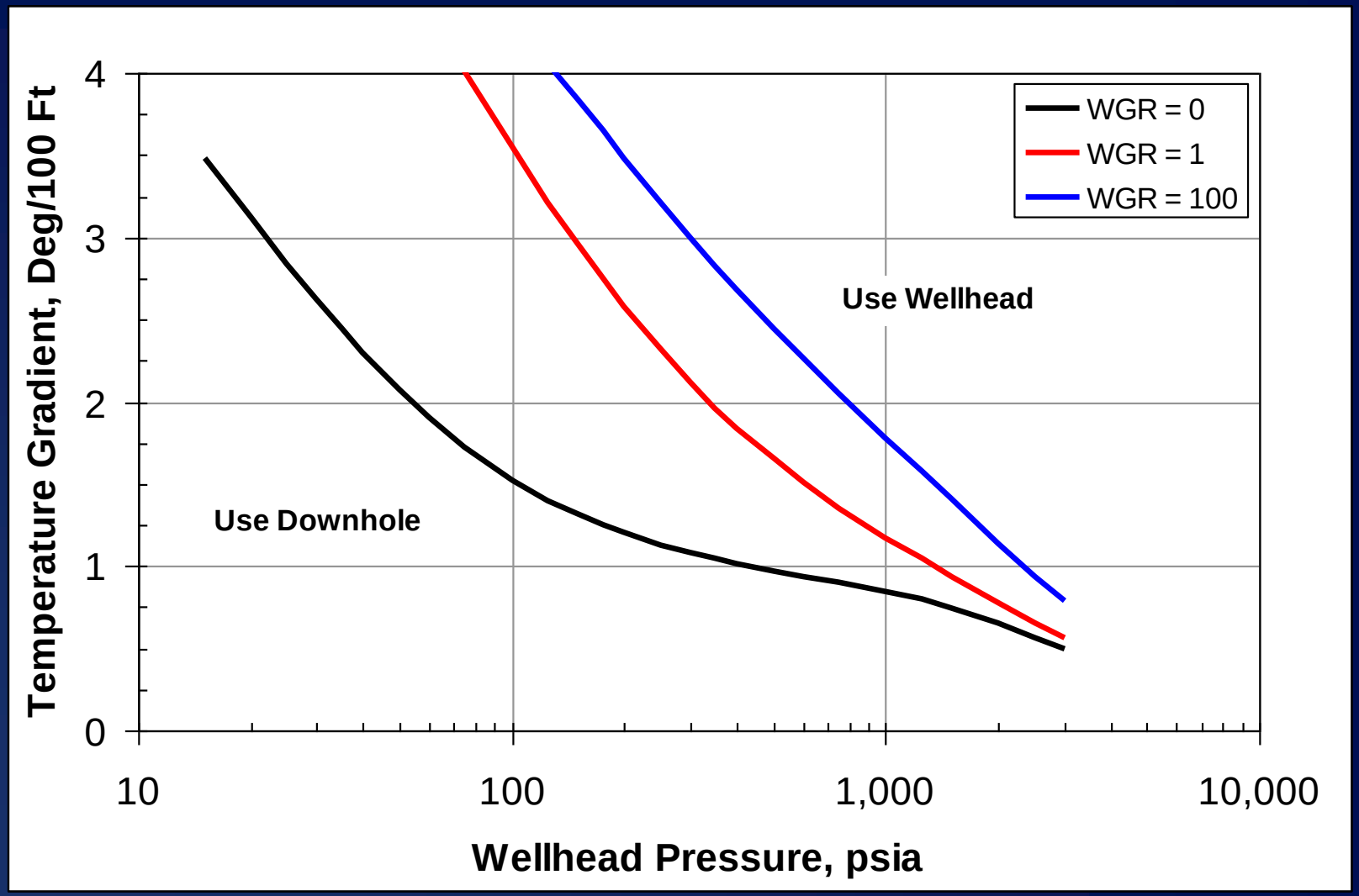
$\Theta$ = hole angle (Deg from vertical)

$v_c$ = critical velocity of liquid droplet, ft/sec

# Well Angle Modification to Turner



# Evaluation Point

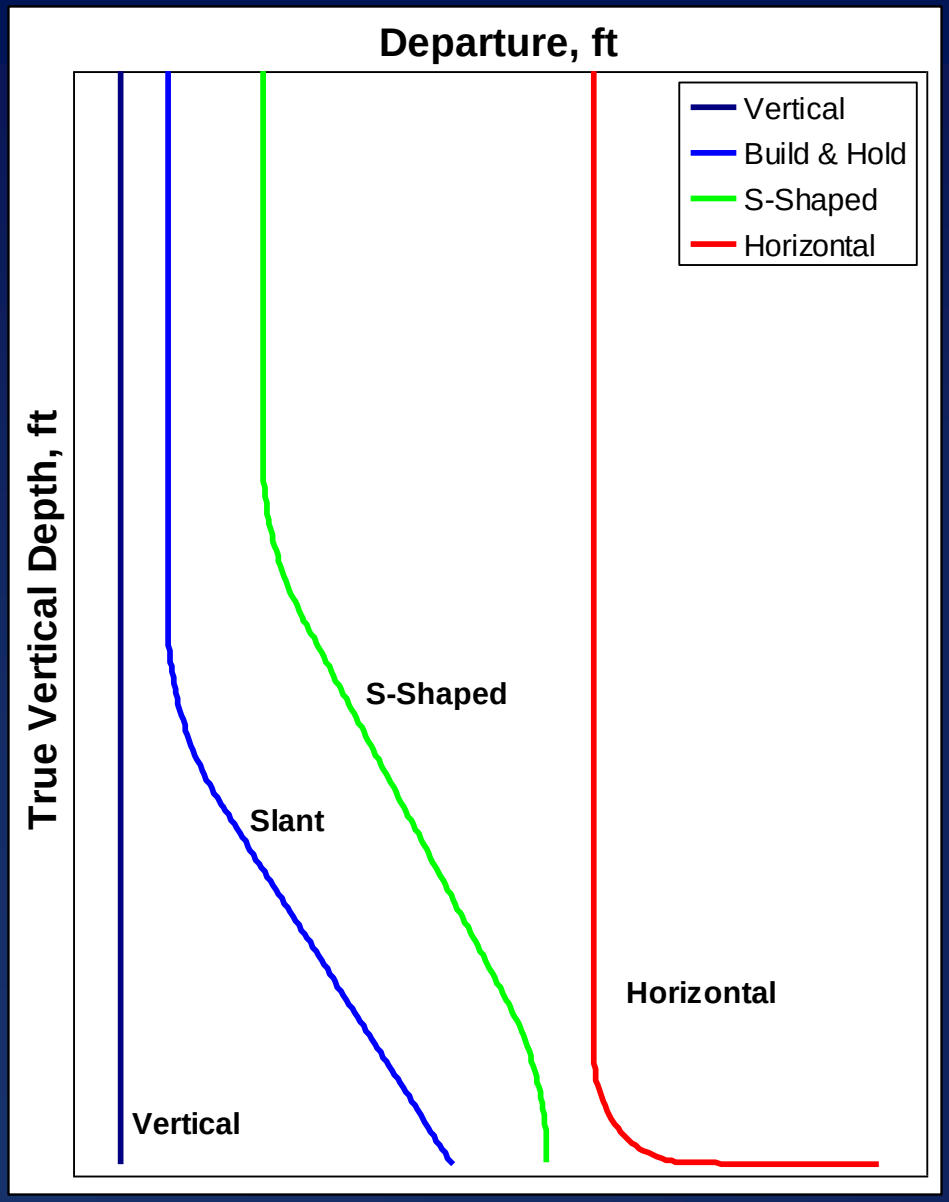



Dtbg = 2.441 in

$\gamma_g$ = 0.65

SPE 120625

# Assorted Well Profiles

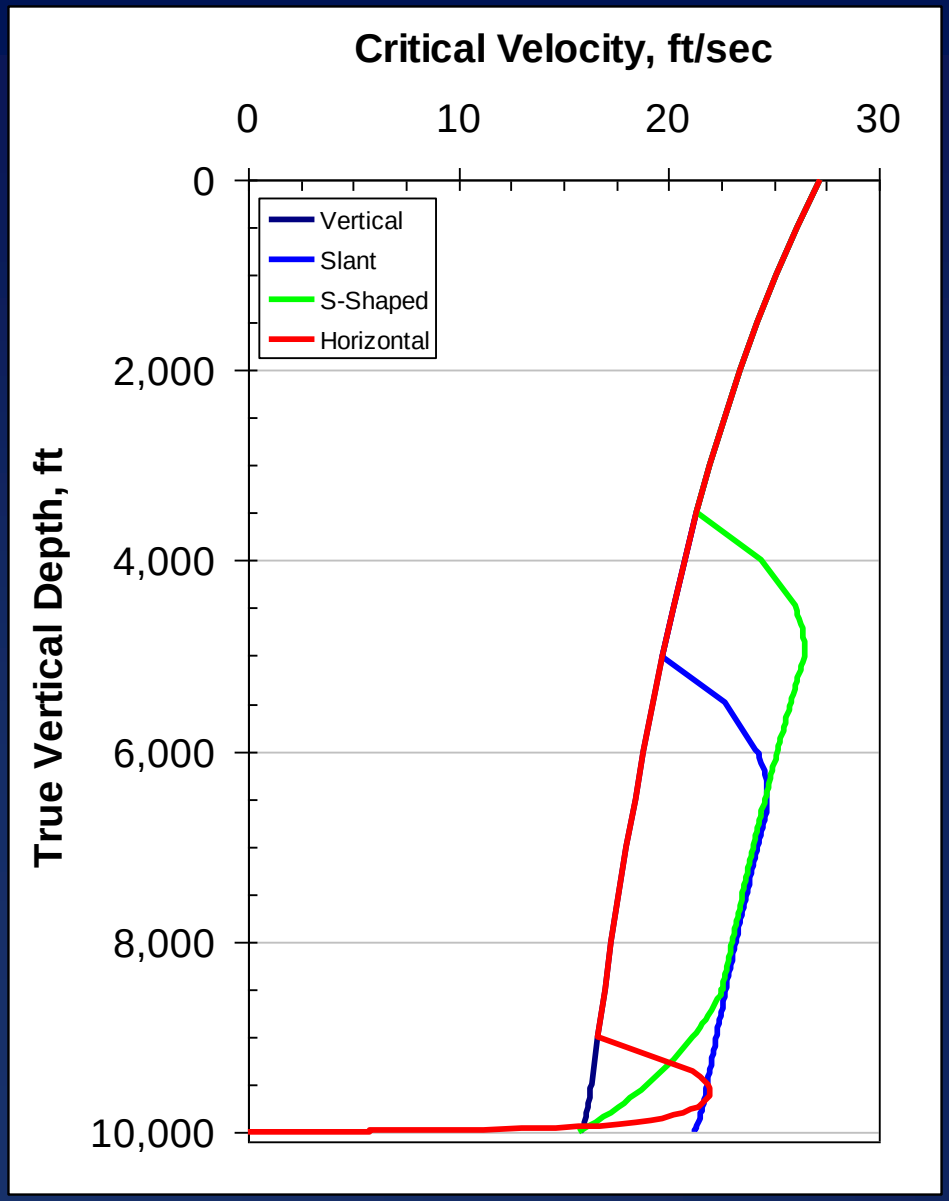



Complex Profiles

- Vertical
- Build & Hold (Slant)
- S-Shaped
- Horizontal

- Complexity increases velocity or rate to unload well

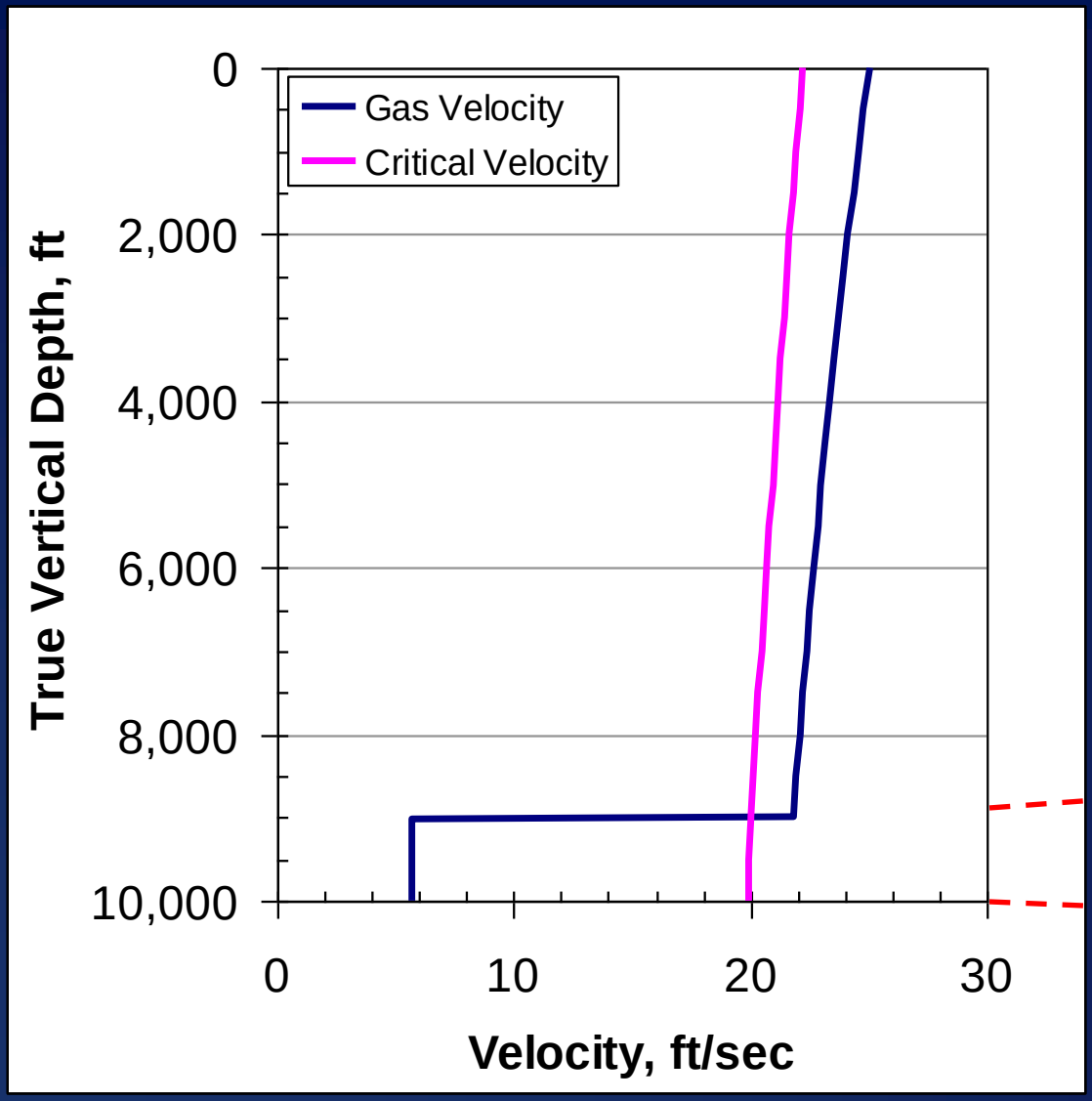
# Example Critical Velocity Profiles

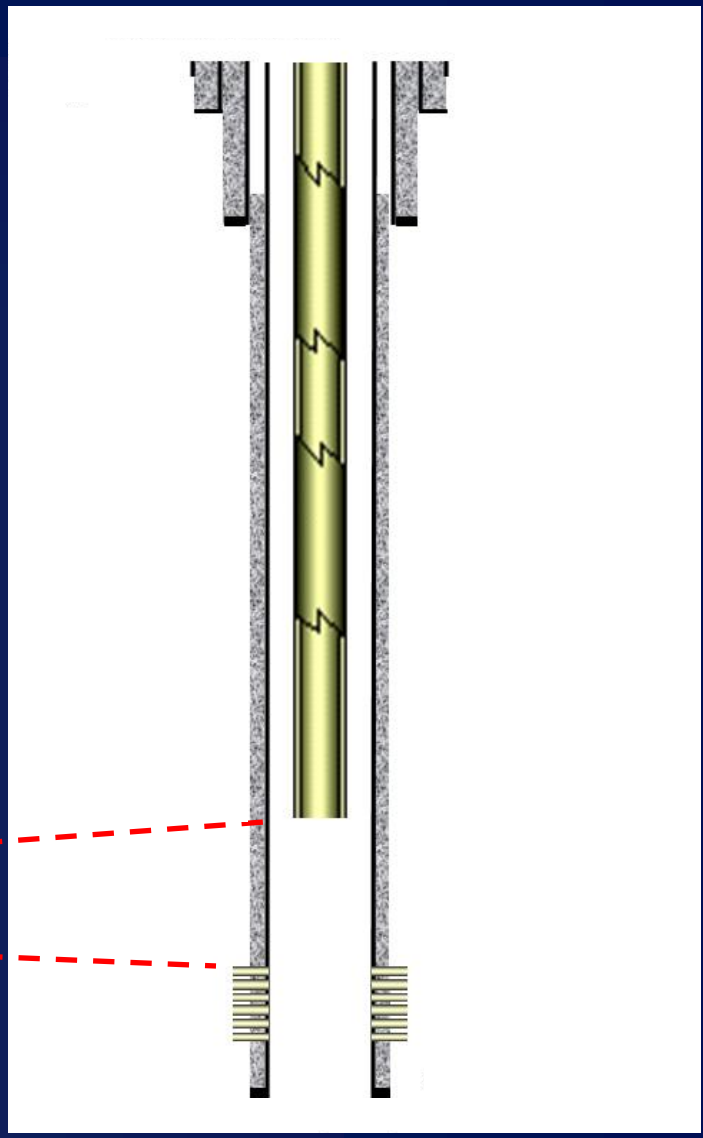



- Effects on critical velocity
  - Pressure
  - Temperature
  - PVT
    - Gas gravity
    - Water salinity
  - Hole Angle

# Vertical Well Case

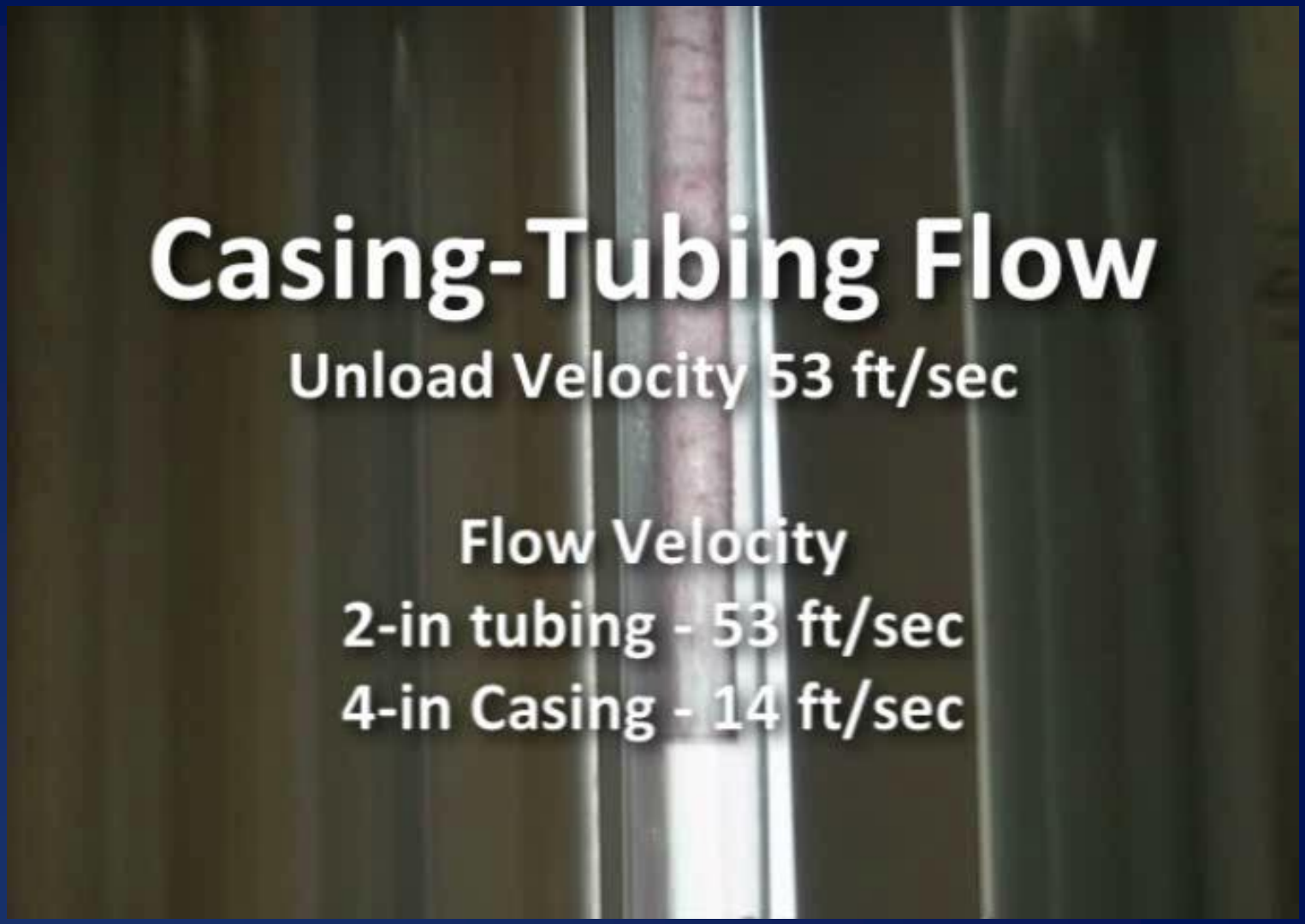
(Variable Tubing Size)



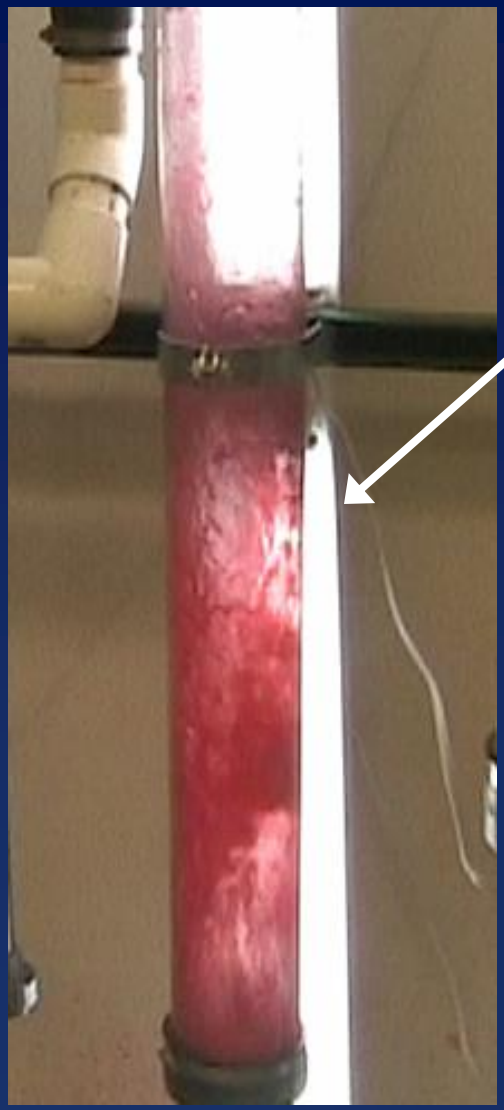
# Liquid Loading

## Bottom of Vertical Well



# Liquid Loading

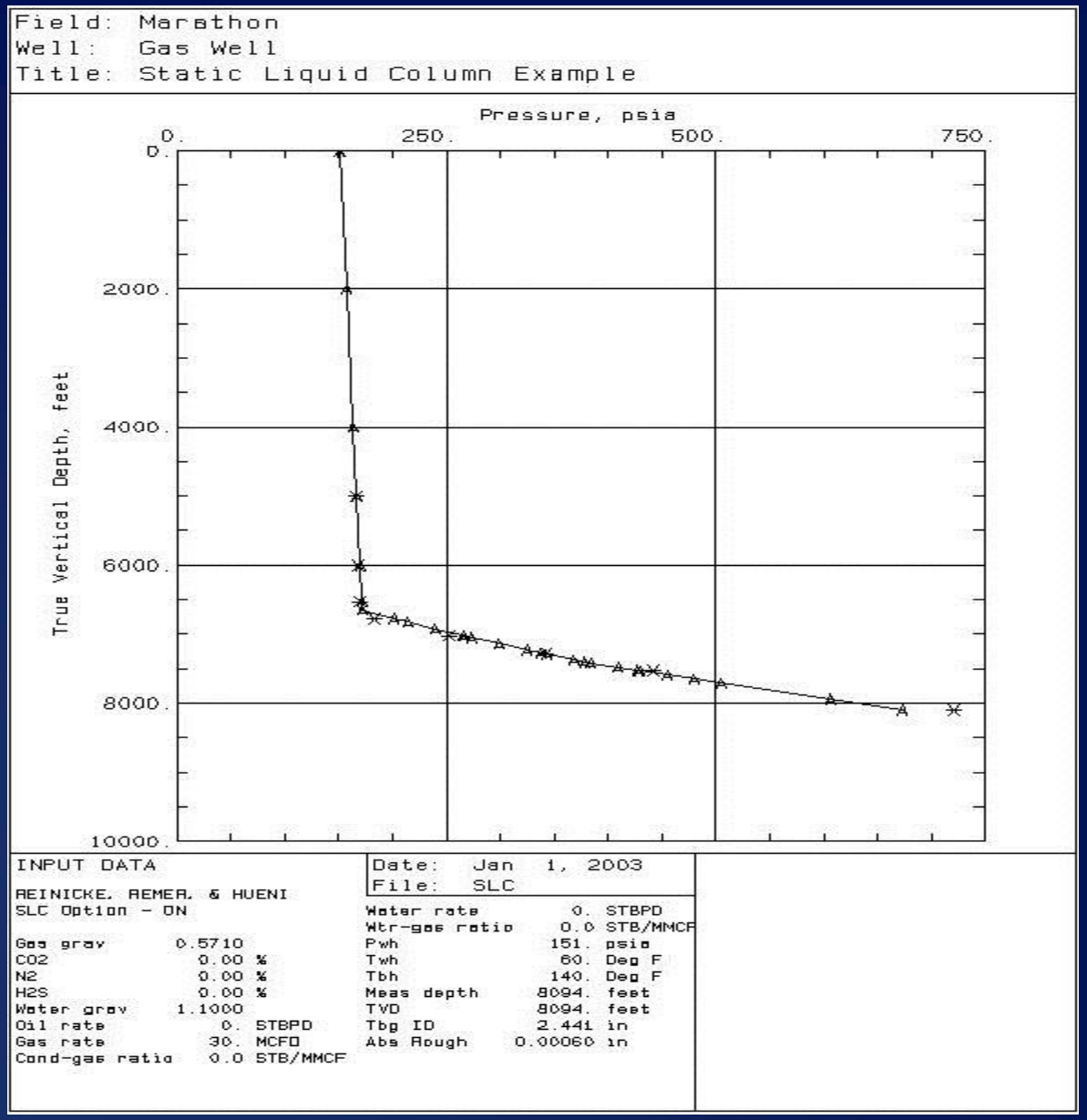
## Bottom of Vertical Well



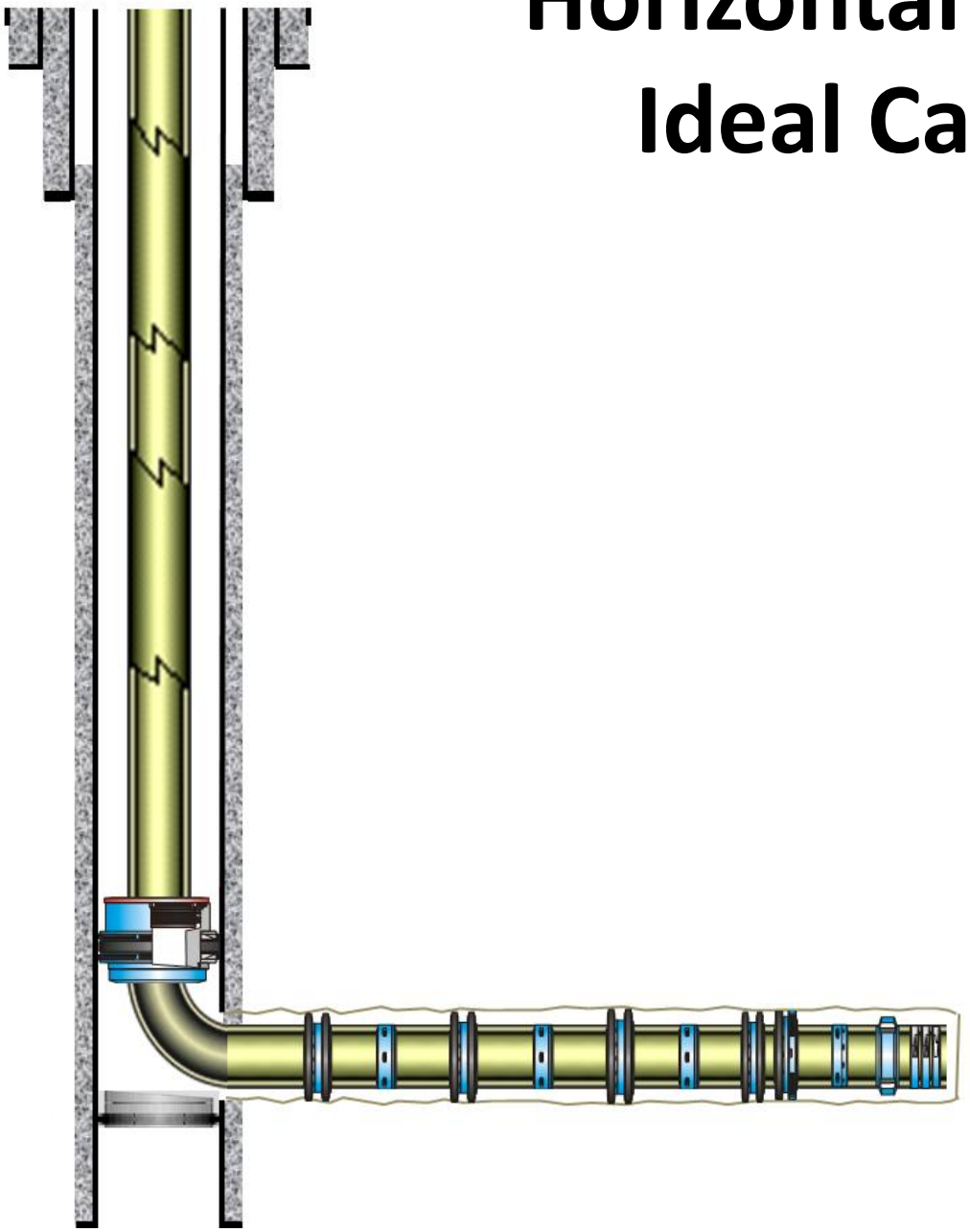
Gas-cut Liquid

Droplets variable size distribution

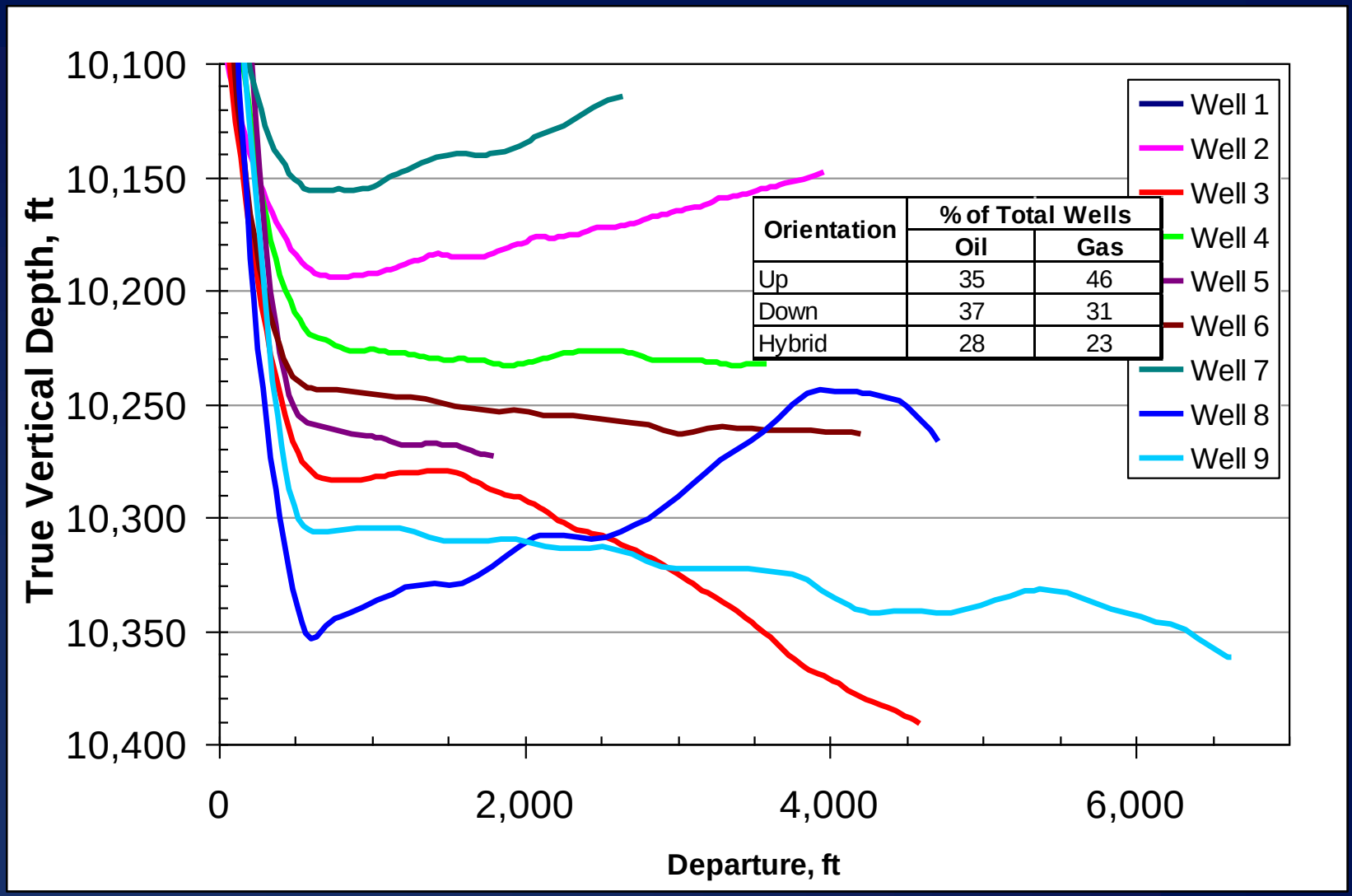
# Static Liquid Column Pressure Profile



# Horizontal Well
# Ideal Case



# Complex Horizontal Well Profiles



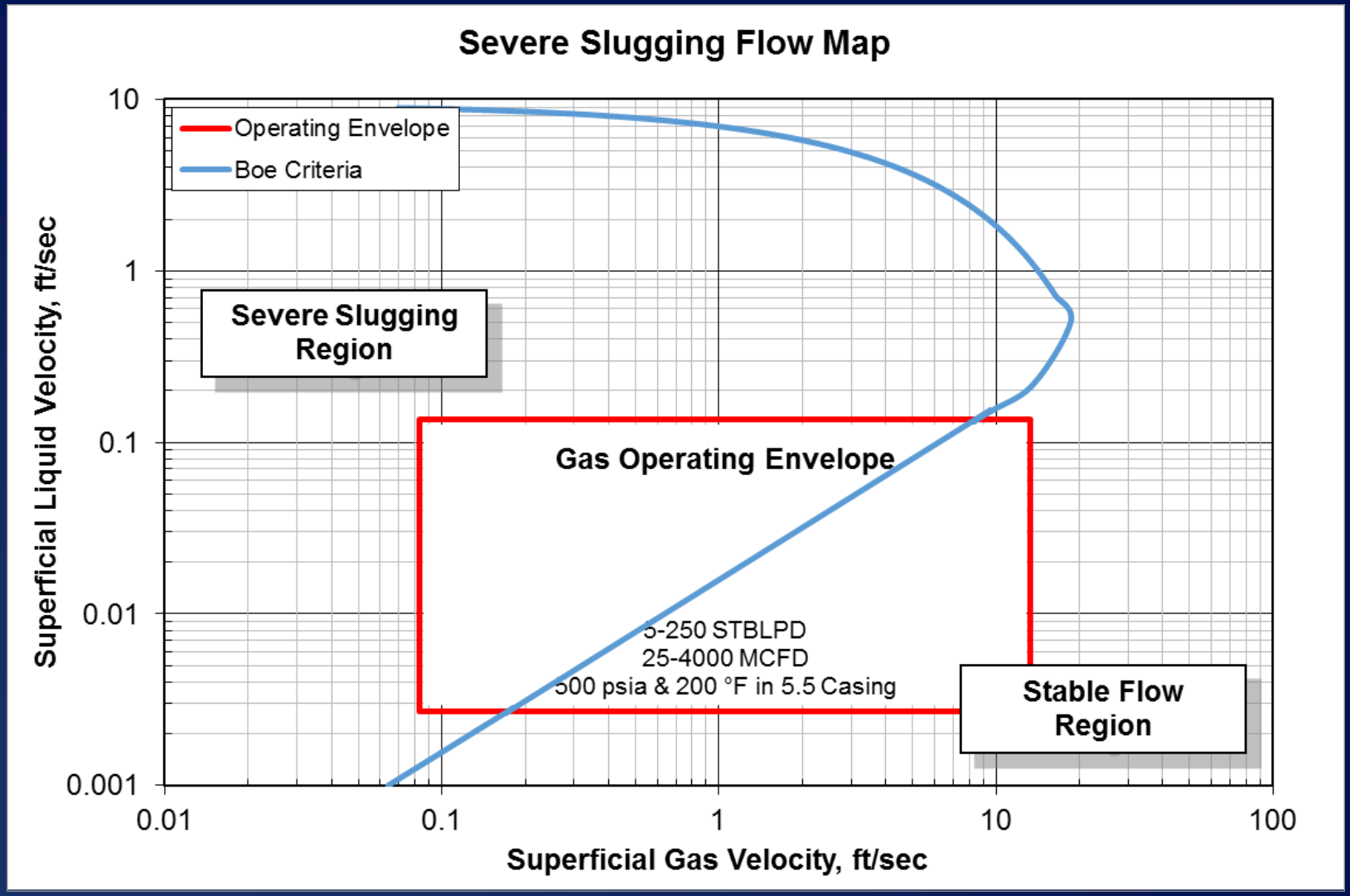

| Orientation | % of Total Wells | |
|---|---|---|
| | Oil | Gas |
| Up | 35 | 46 |
| Down | 37 | 31 |
| Hybrid | 28 | 23 |

# Horizontal Well Profiles

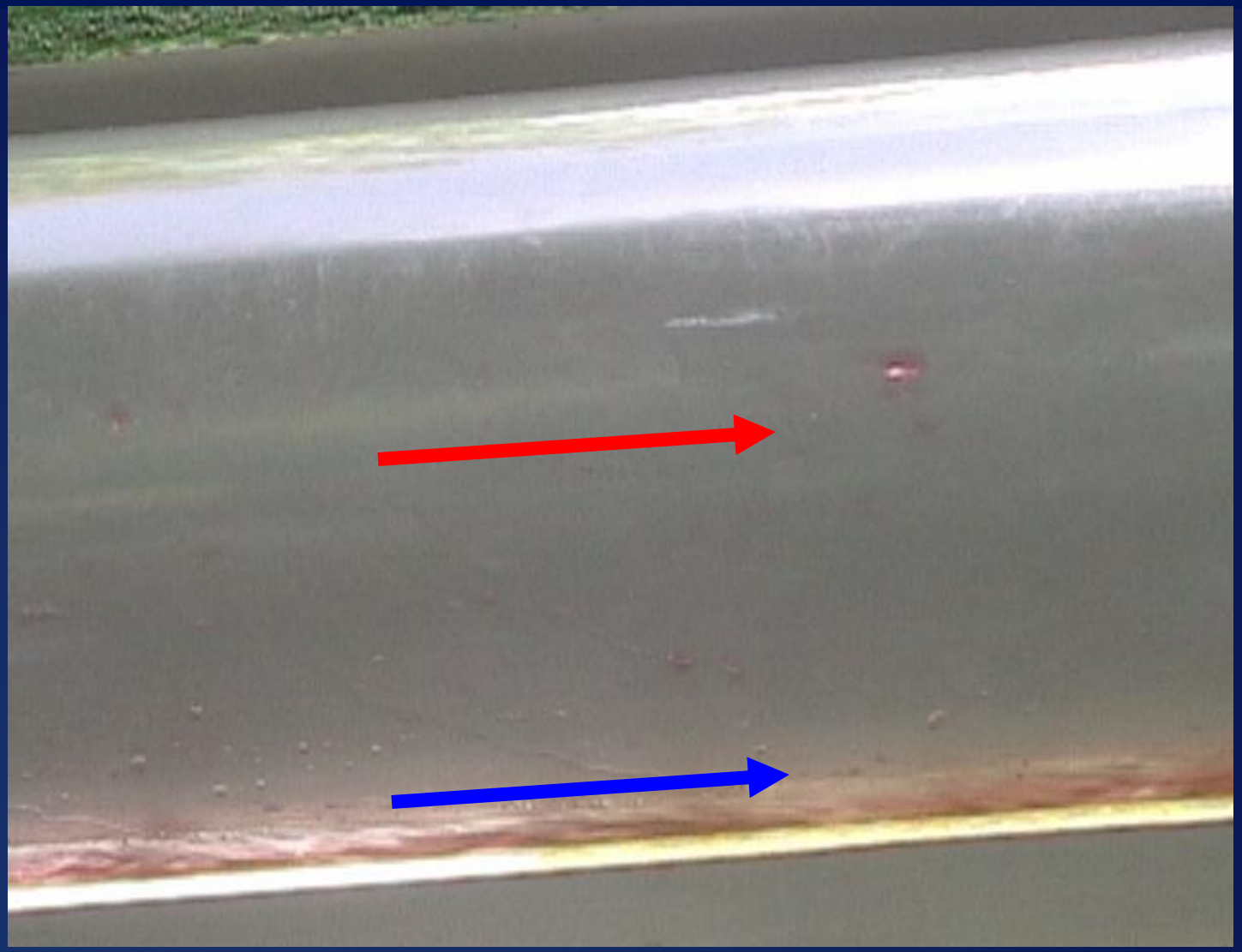
**Marcellus**

**Horizontal Well Geometry**

# Severe Slugging



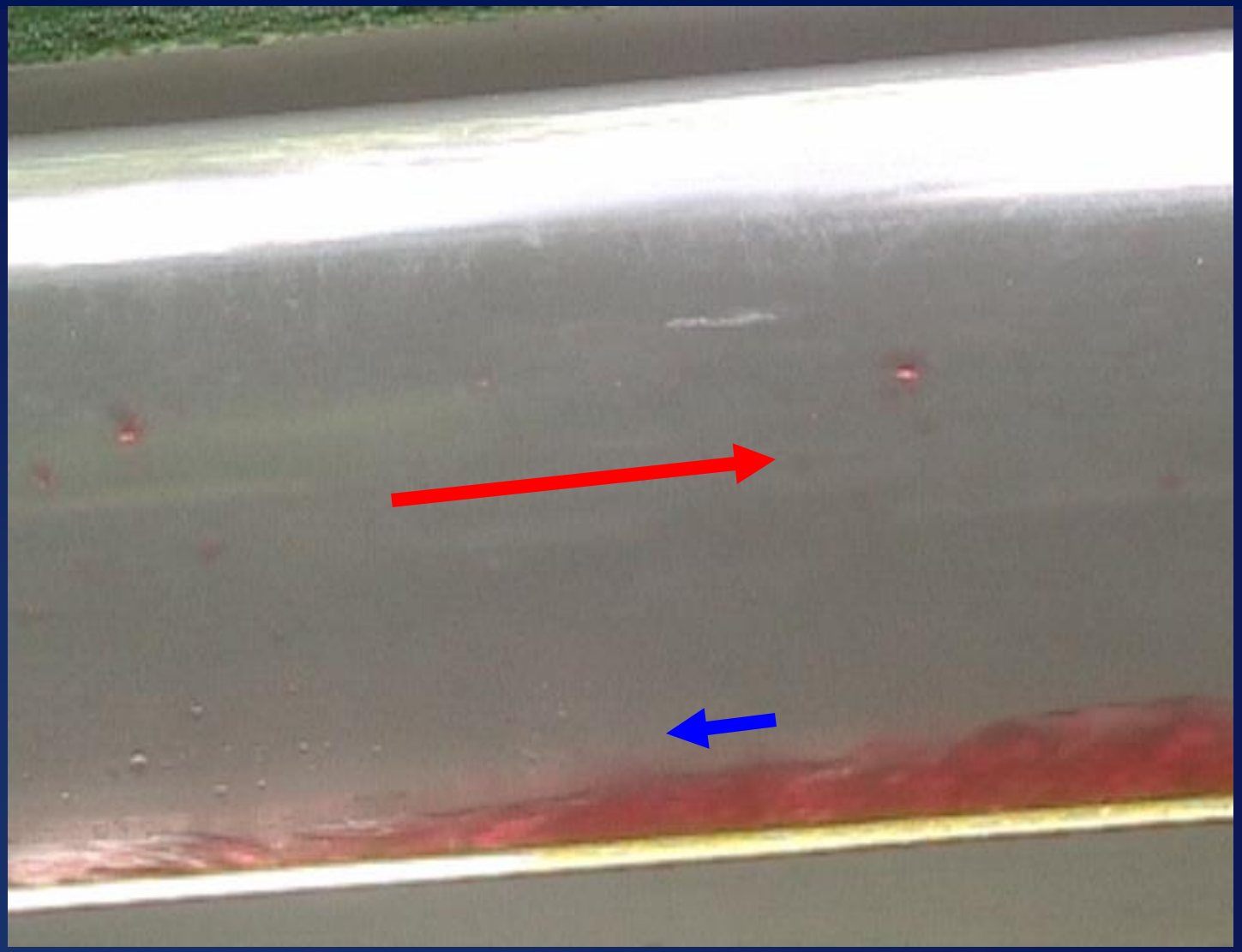
# Liquid Loading at 86° from Vertical



4-in Pipe

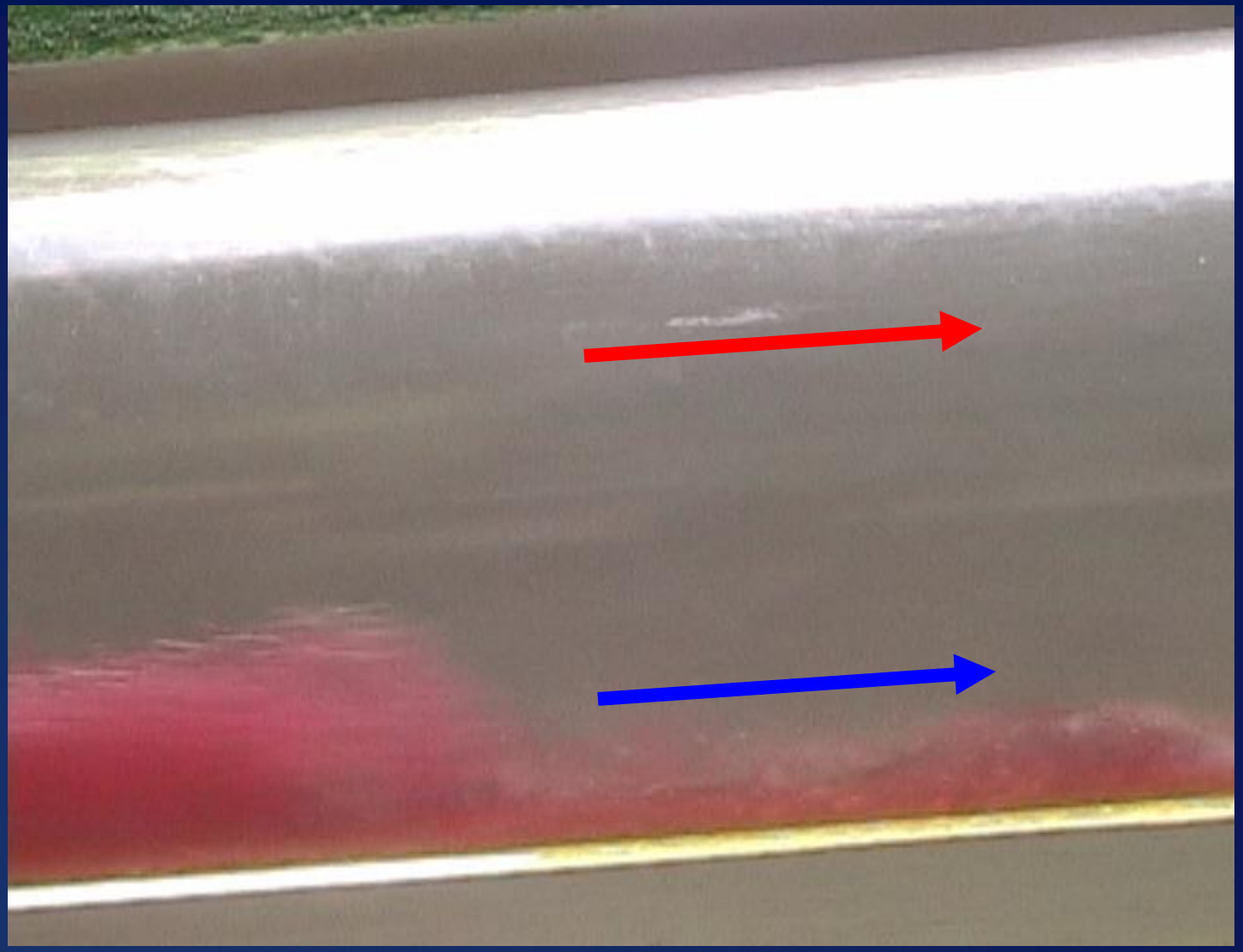
Stratified flow pattern

# Liquid Loading at 86° from Vertical



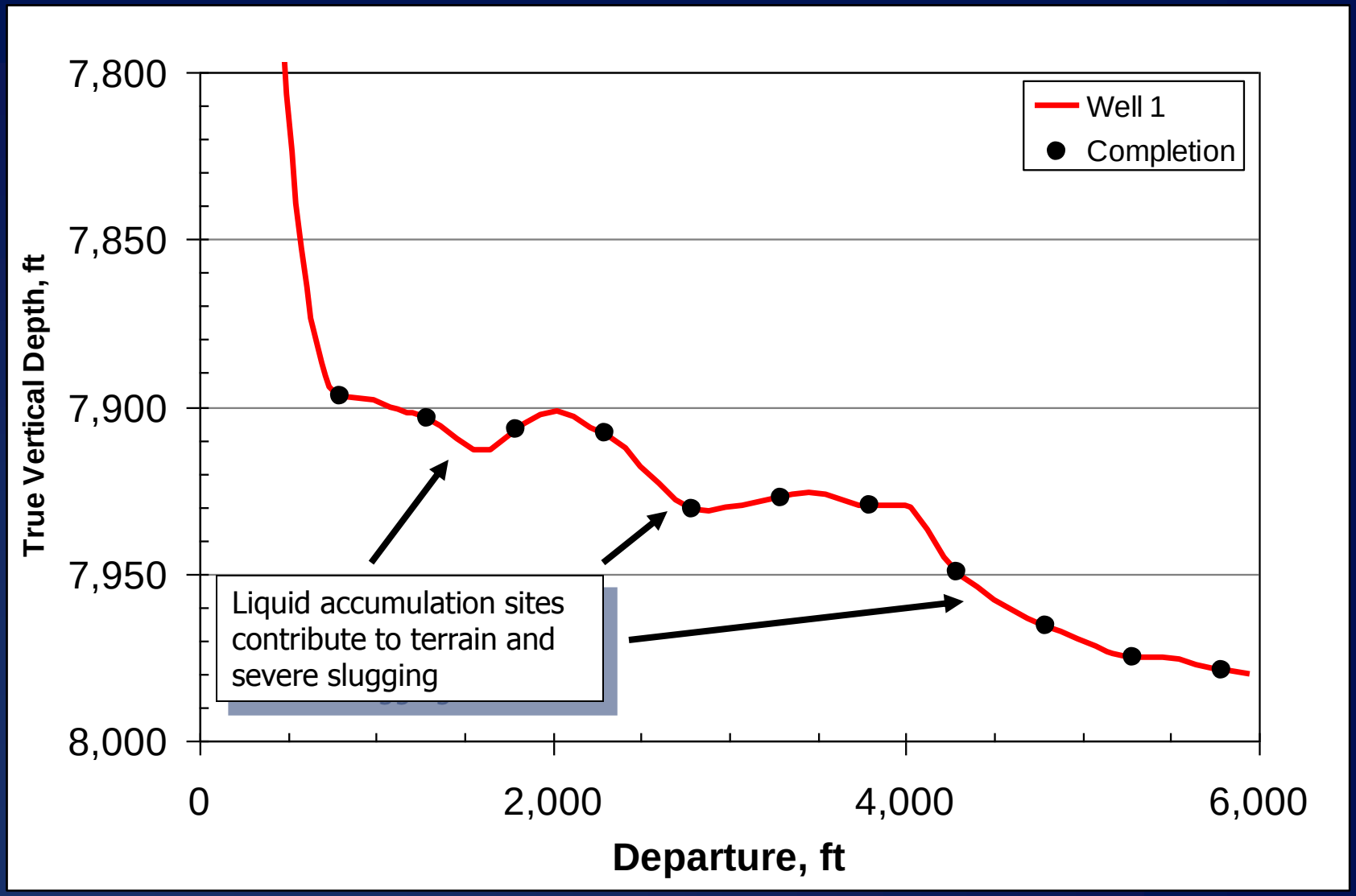
Liquid accumulation at gas velocity less than critical

# Liquid Loading at 86° from Vertical

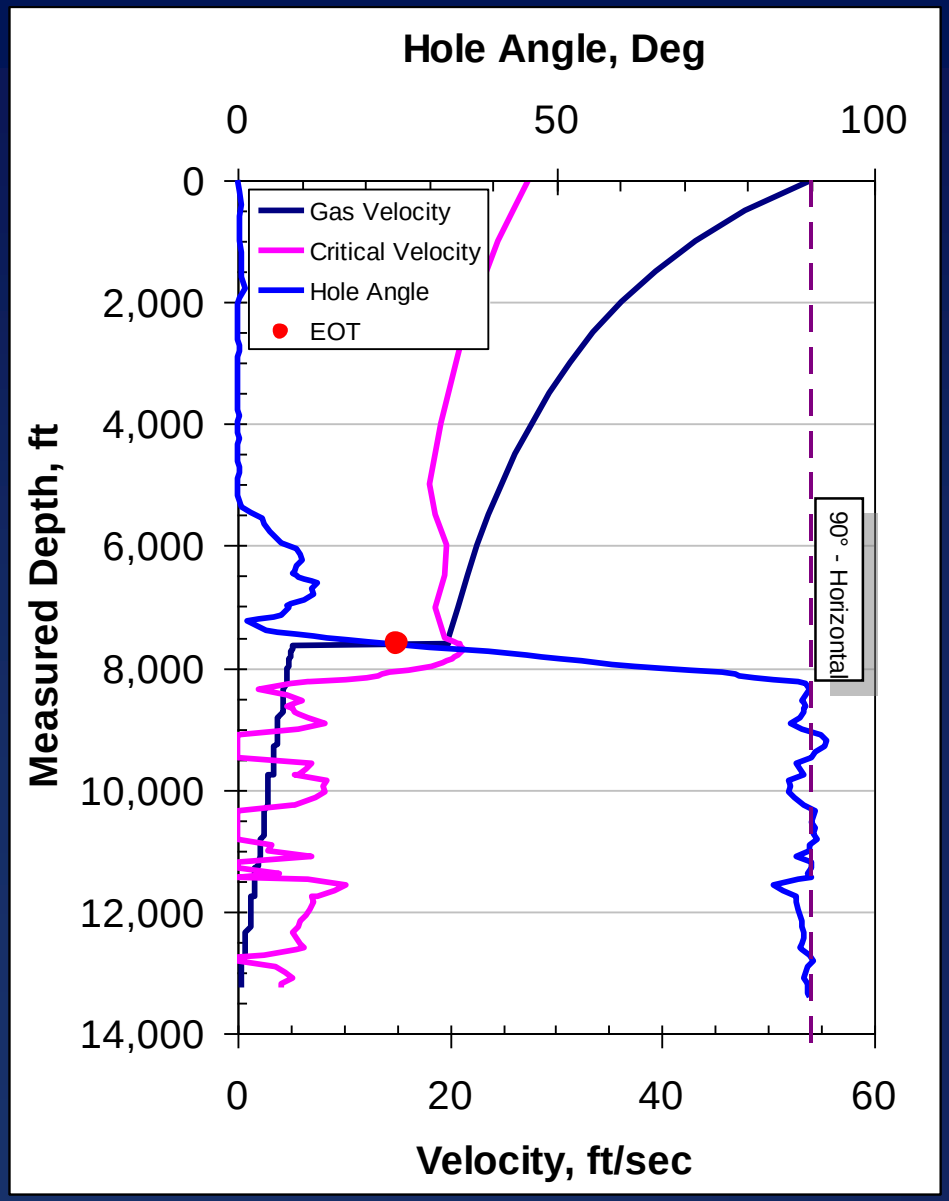


Onset of terrain slugging

# Example Horizontal Well

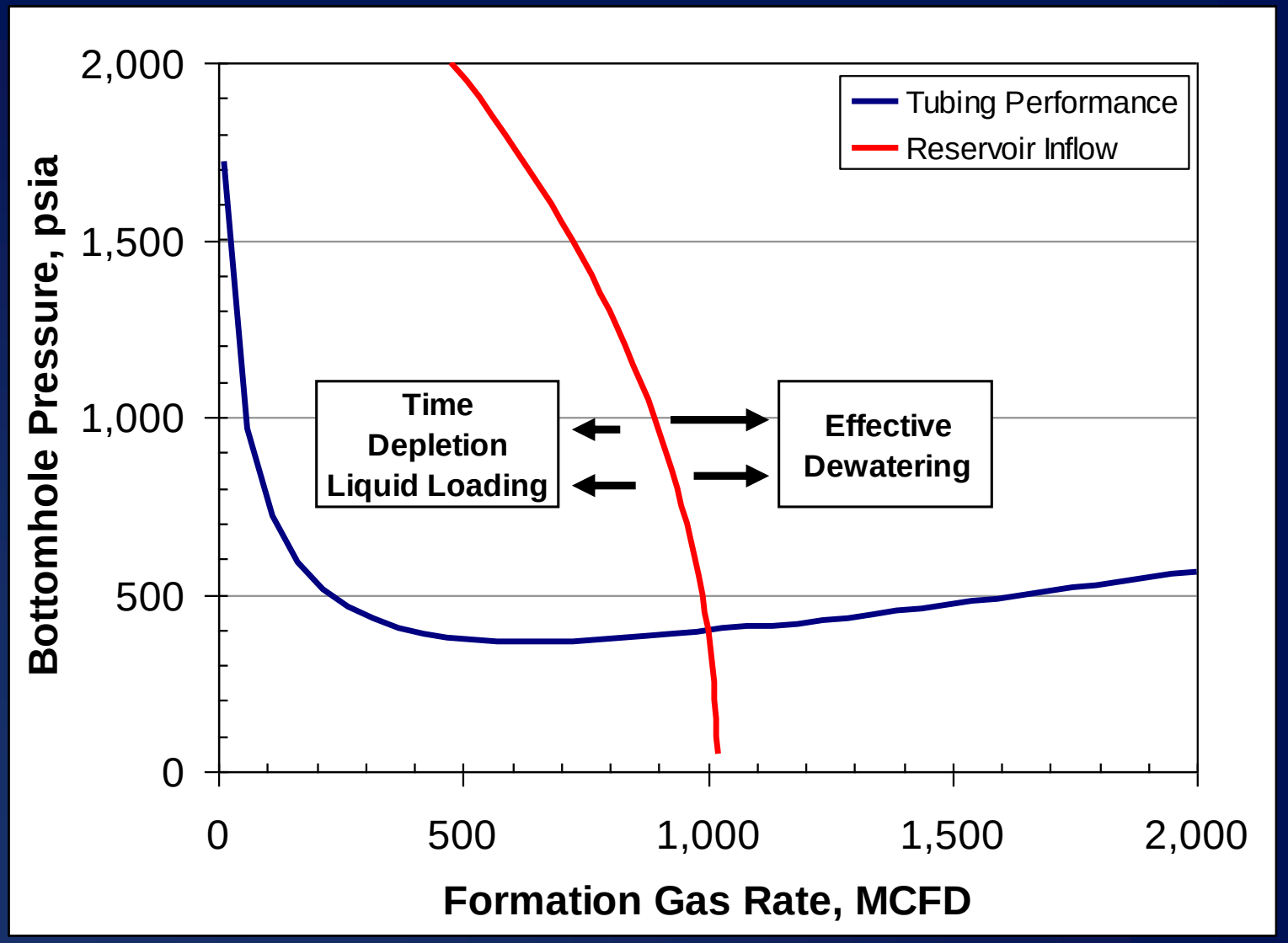


# Example Horizontal Well

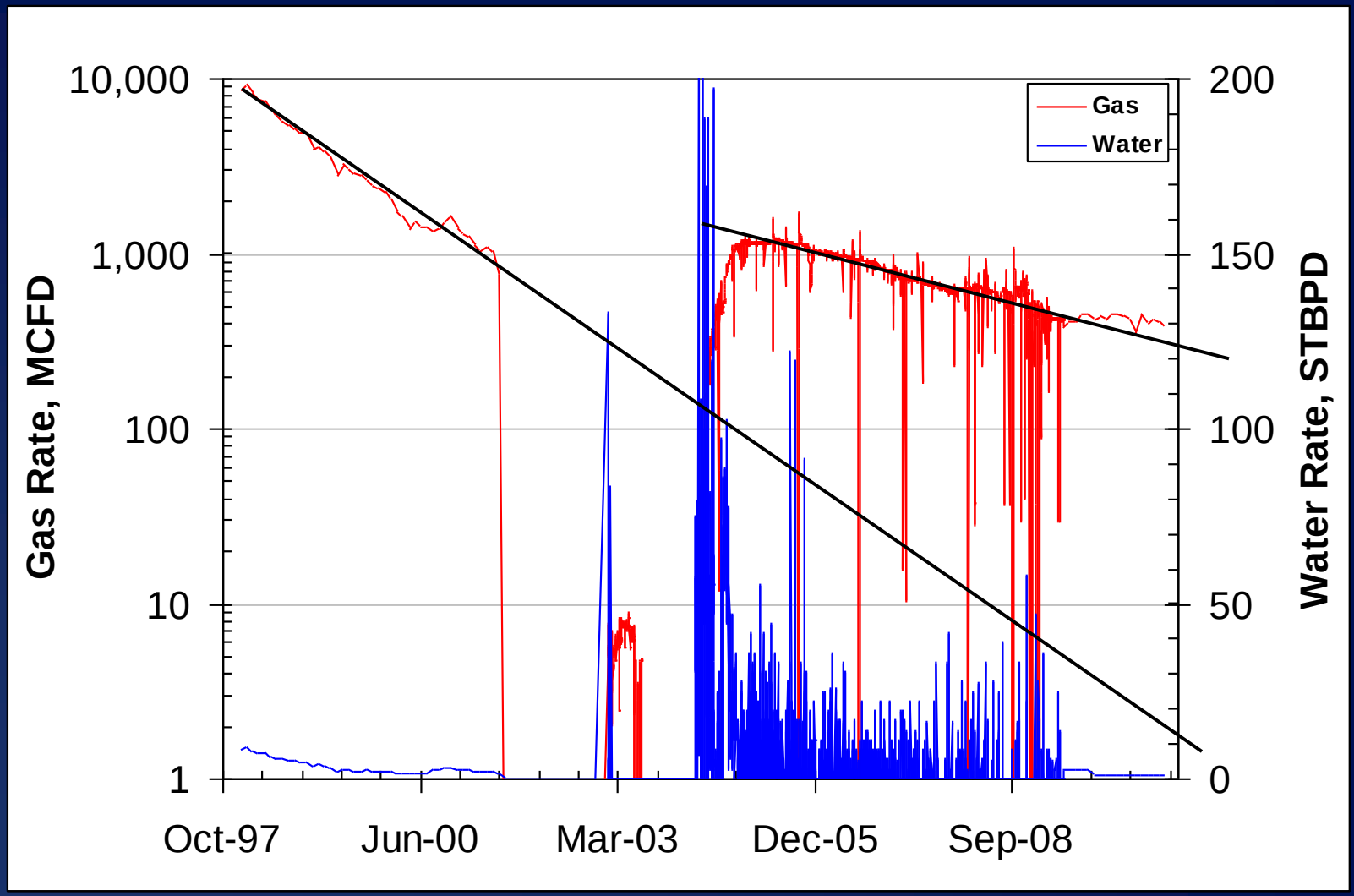



- Velocity profile
- Gas velocity
  - Comparison with critical velocity
- EOT at 25°
  - Shallow
  - Slugging in curve
  - Slugging in horizontal

# Factors Affecting Rate-Time Decline



# Example of Successful Deliquification Program



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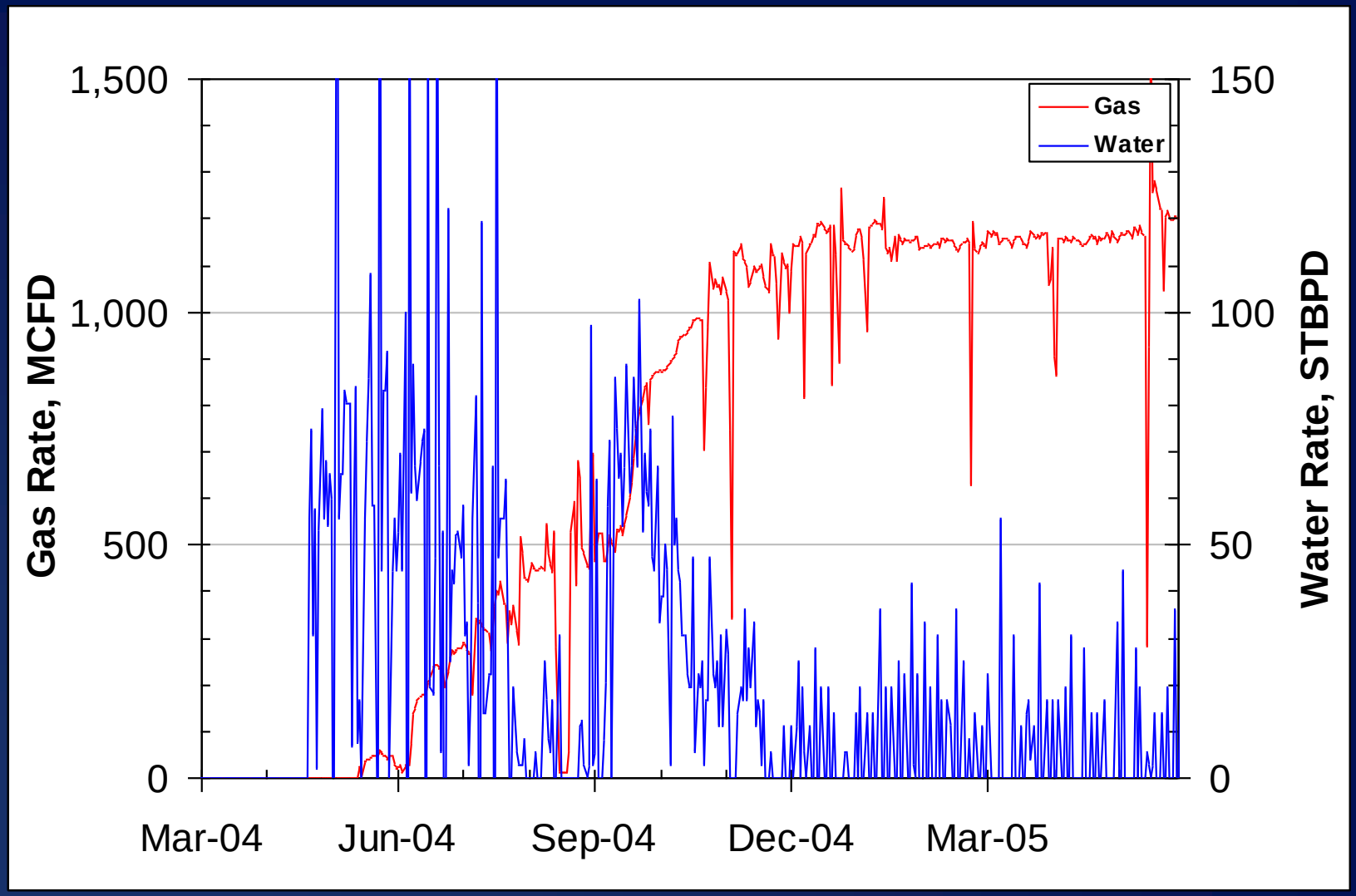

# Possible Solutions

- Velocity management
- Compression
- Foamers
- Artificial lift

# Observations

- Complex Geometries require Higher Critical Velocity
- Proper Liquids Management offers significant benefit
- Liquids Management restores / maintains well productivity
- Liquids Management requires constant attention
- Determine Critical Velocity / Rate thru-out well
- Nodal Analysis offers insight to Long Term Performance

# Questions?

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