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Distinguished Lecturer Program
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Understanding Liquid Loading Will Improve Well Performance

Rob Sutton

Society of Petroleum Engineers
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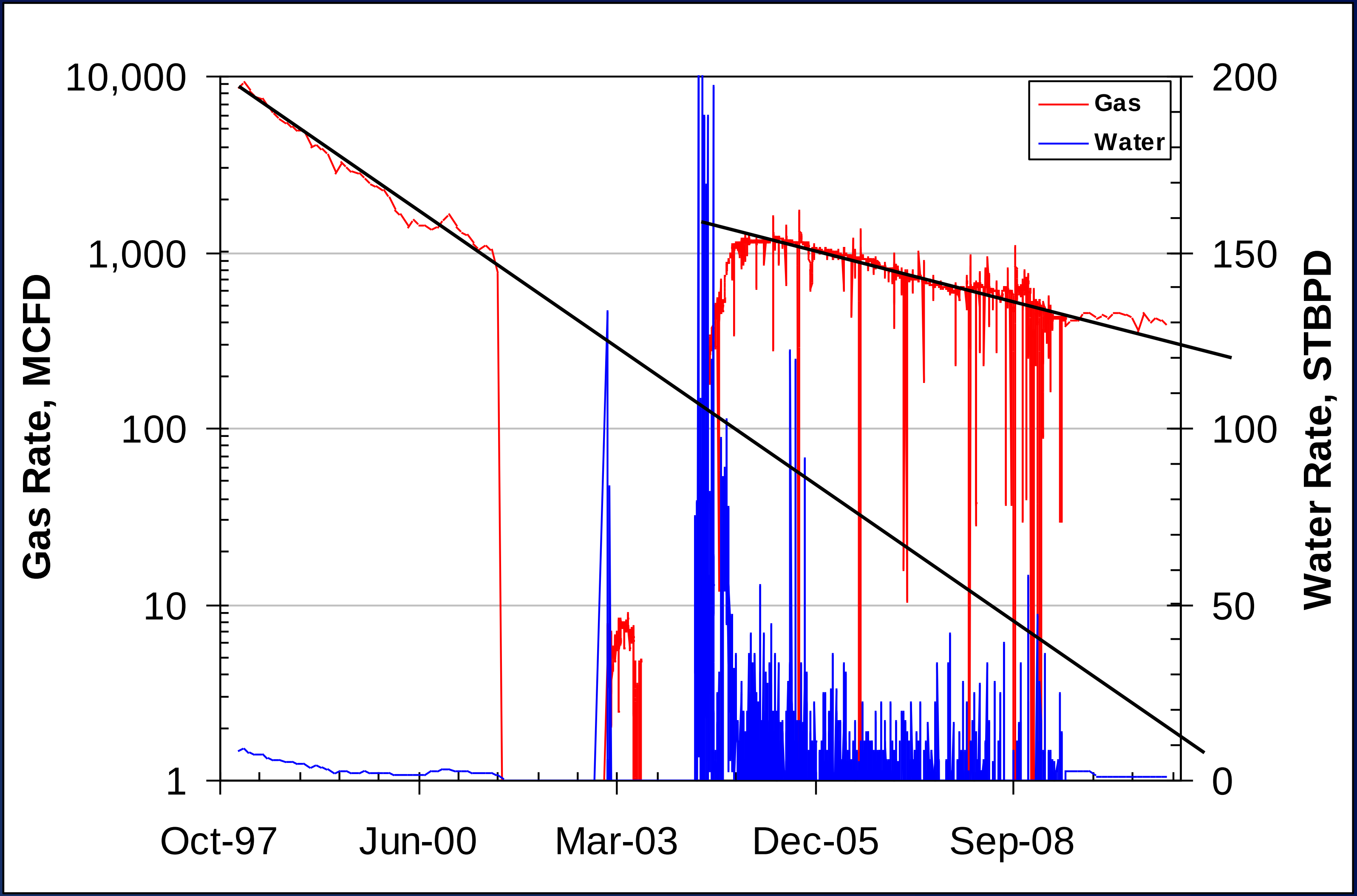
Example of Successful Deliquification Program

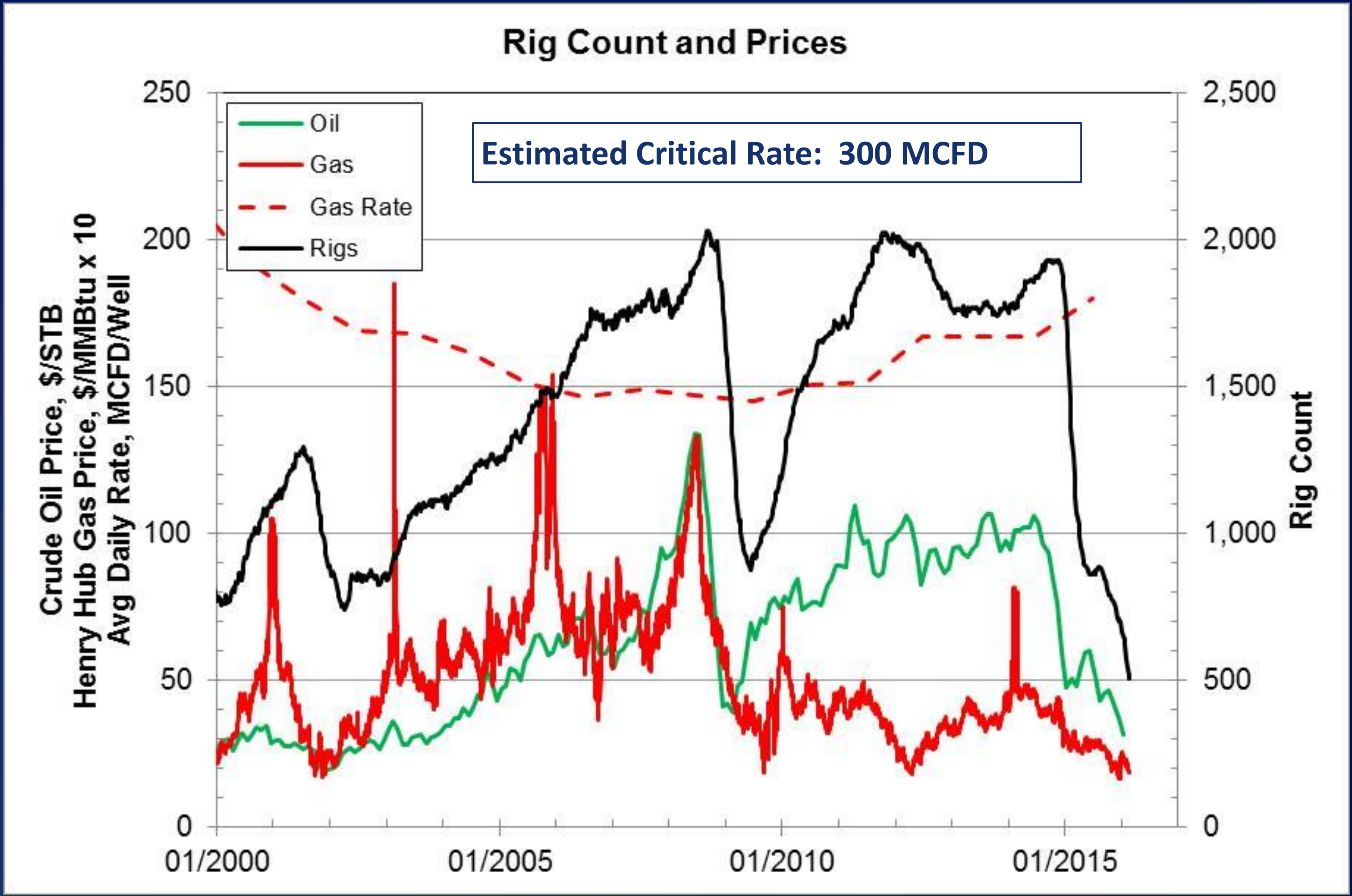


Purpose

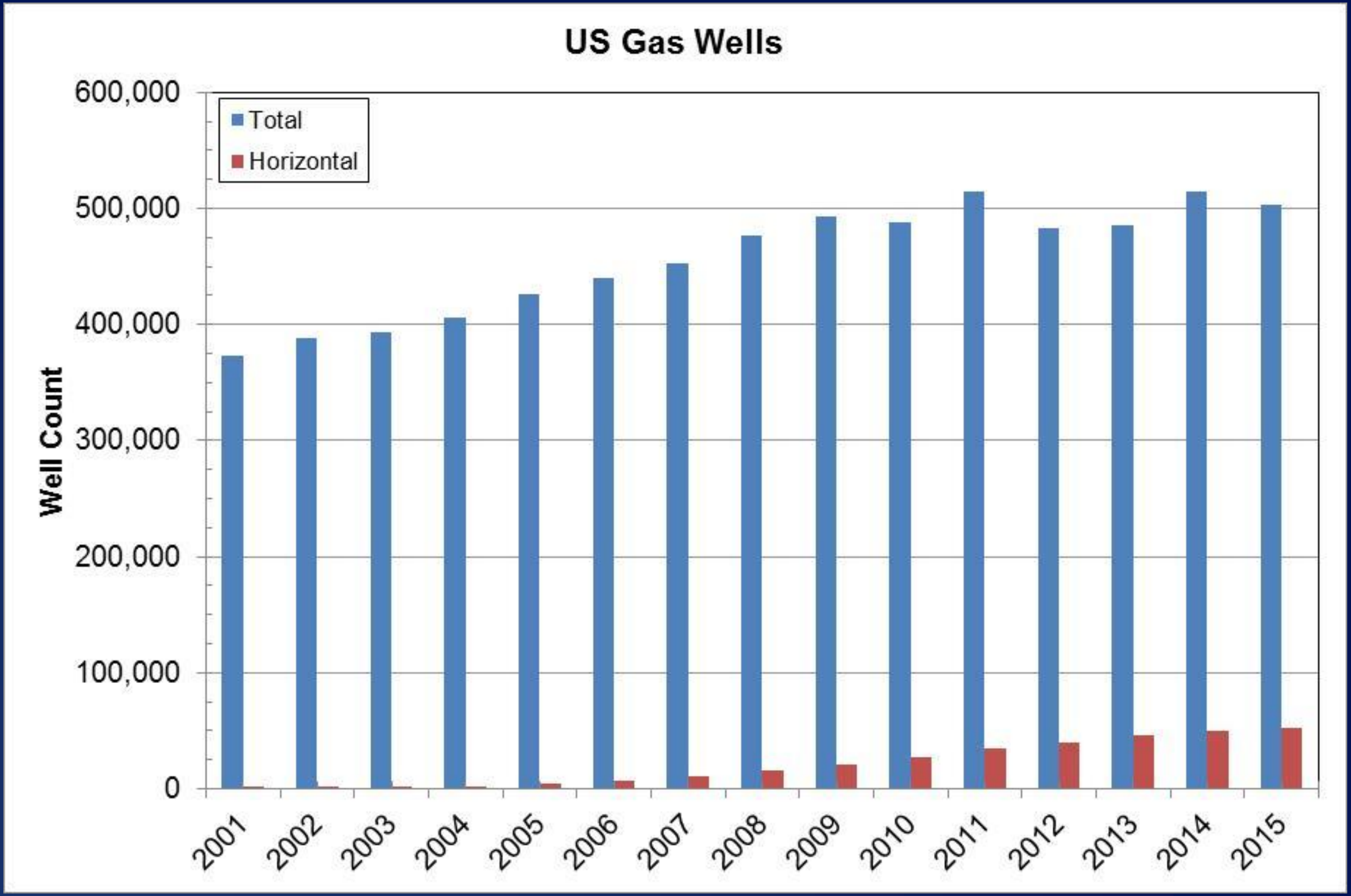
Address the following question:

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

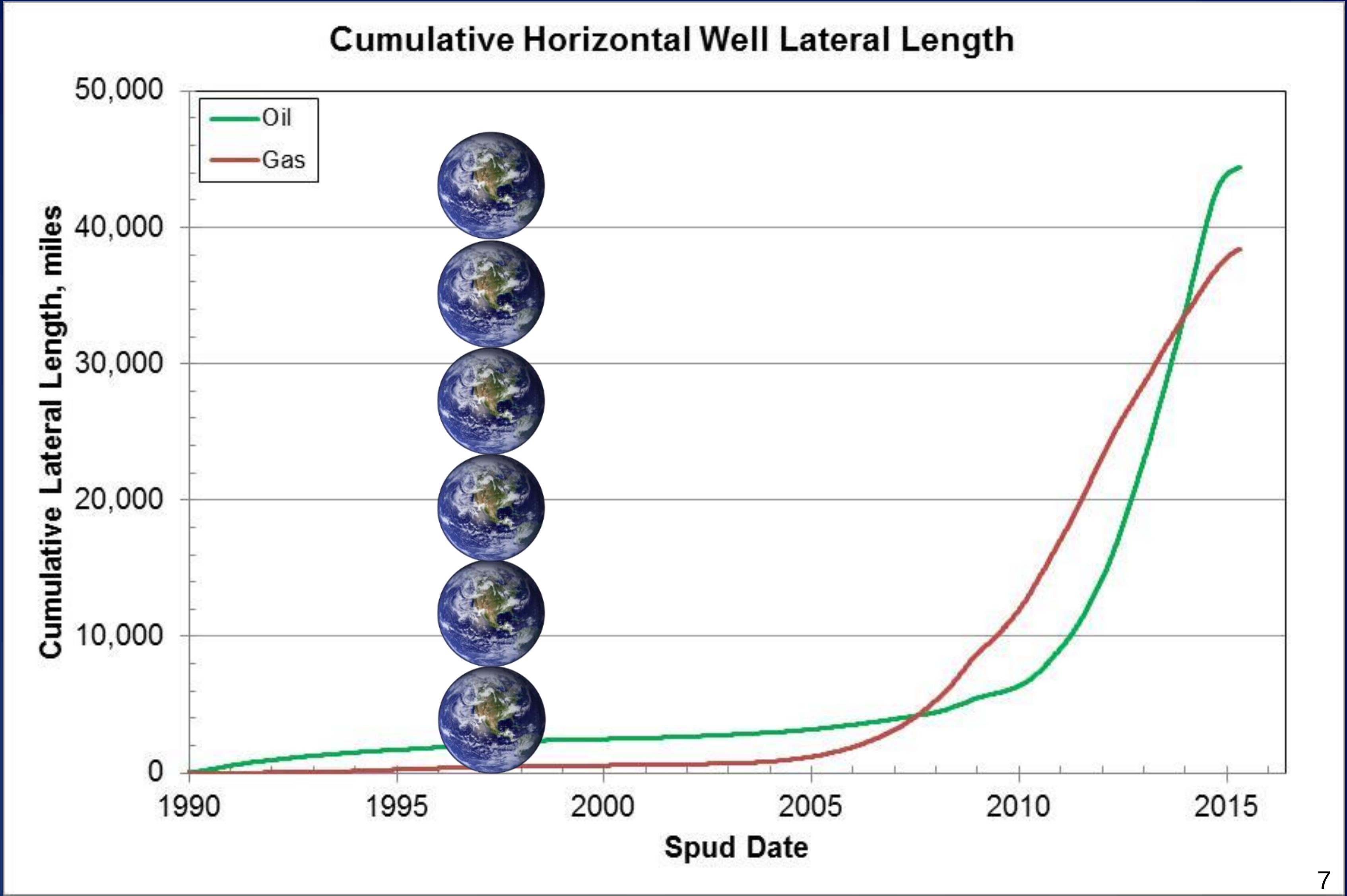
State of the Industry - USA



Well Inventory - USA



Lateral Length



Terminology

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

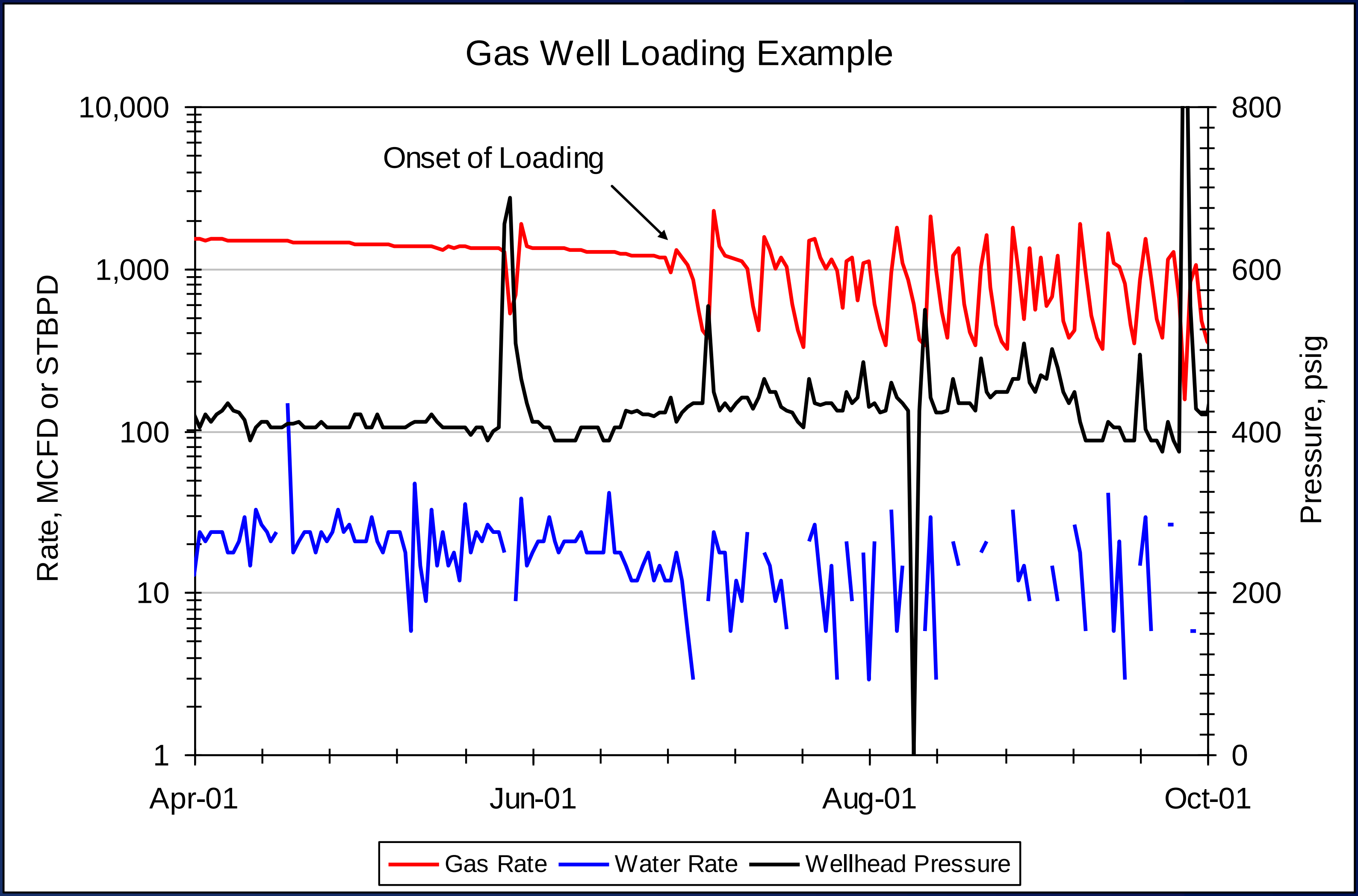
Analysis Techniques

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

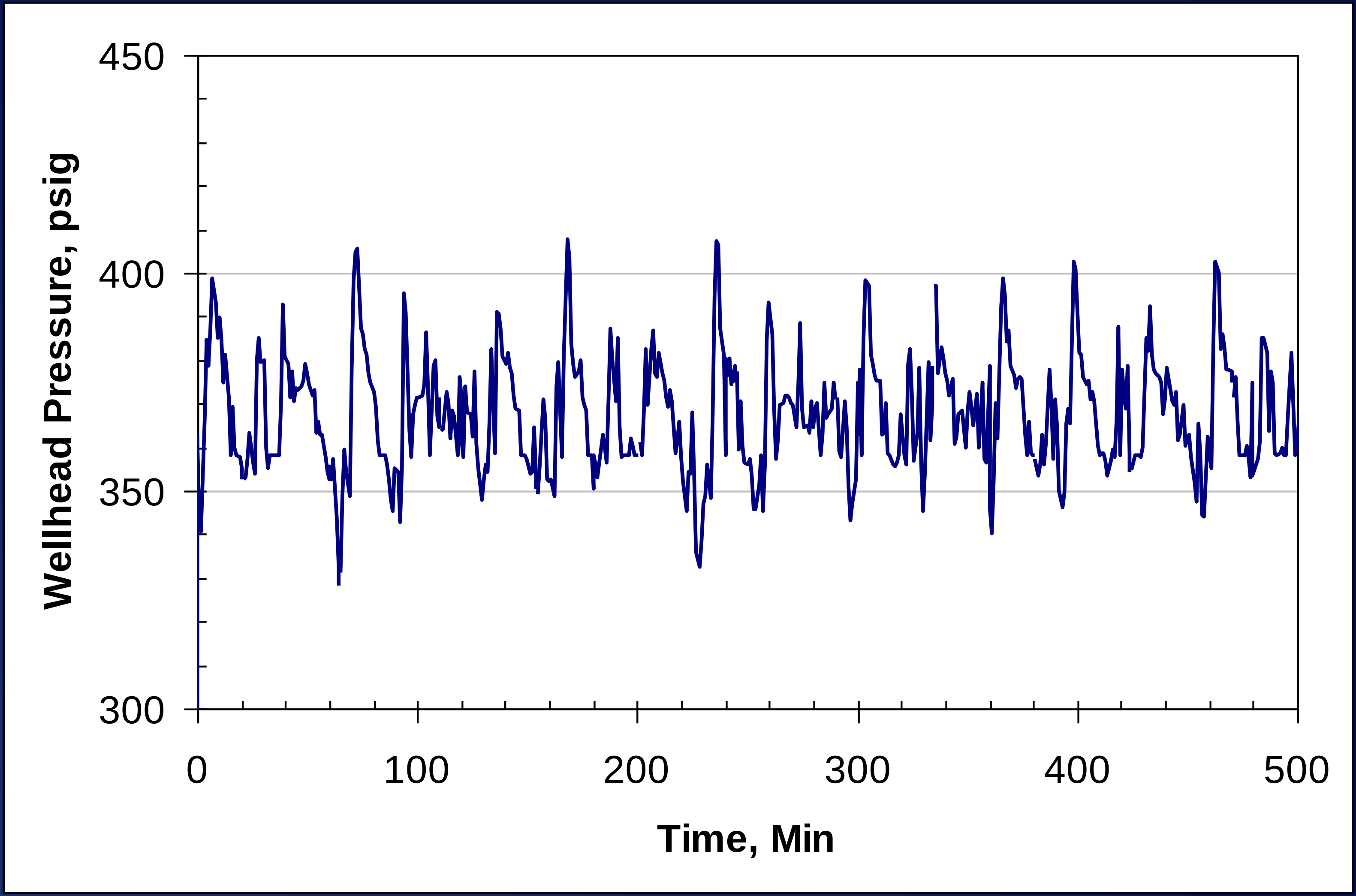
Complications

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

Production Data

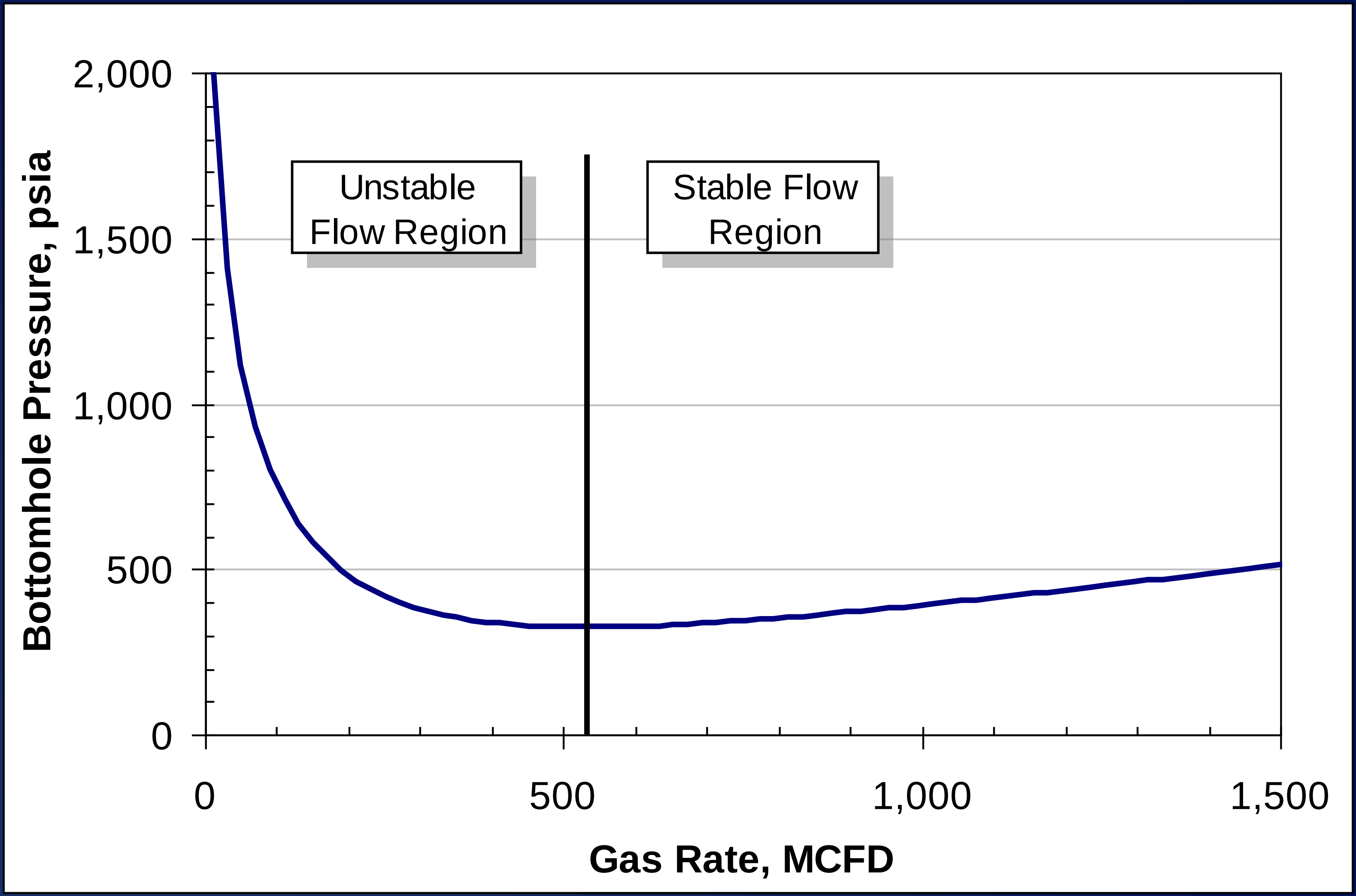


Pressure Data

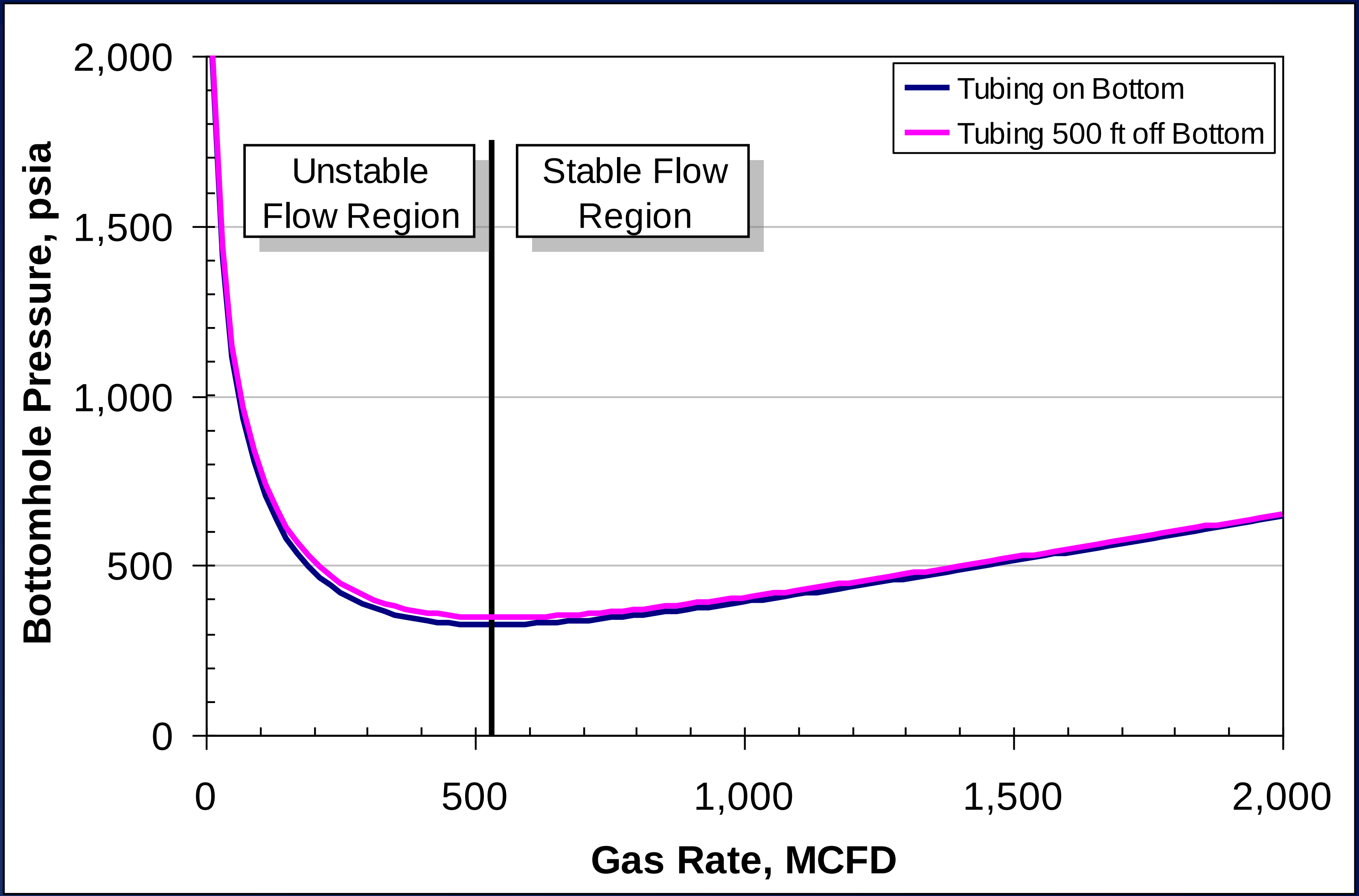


Critical Rate

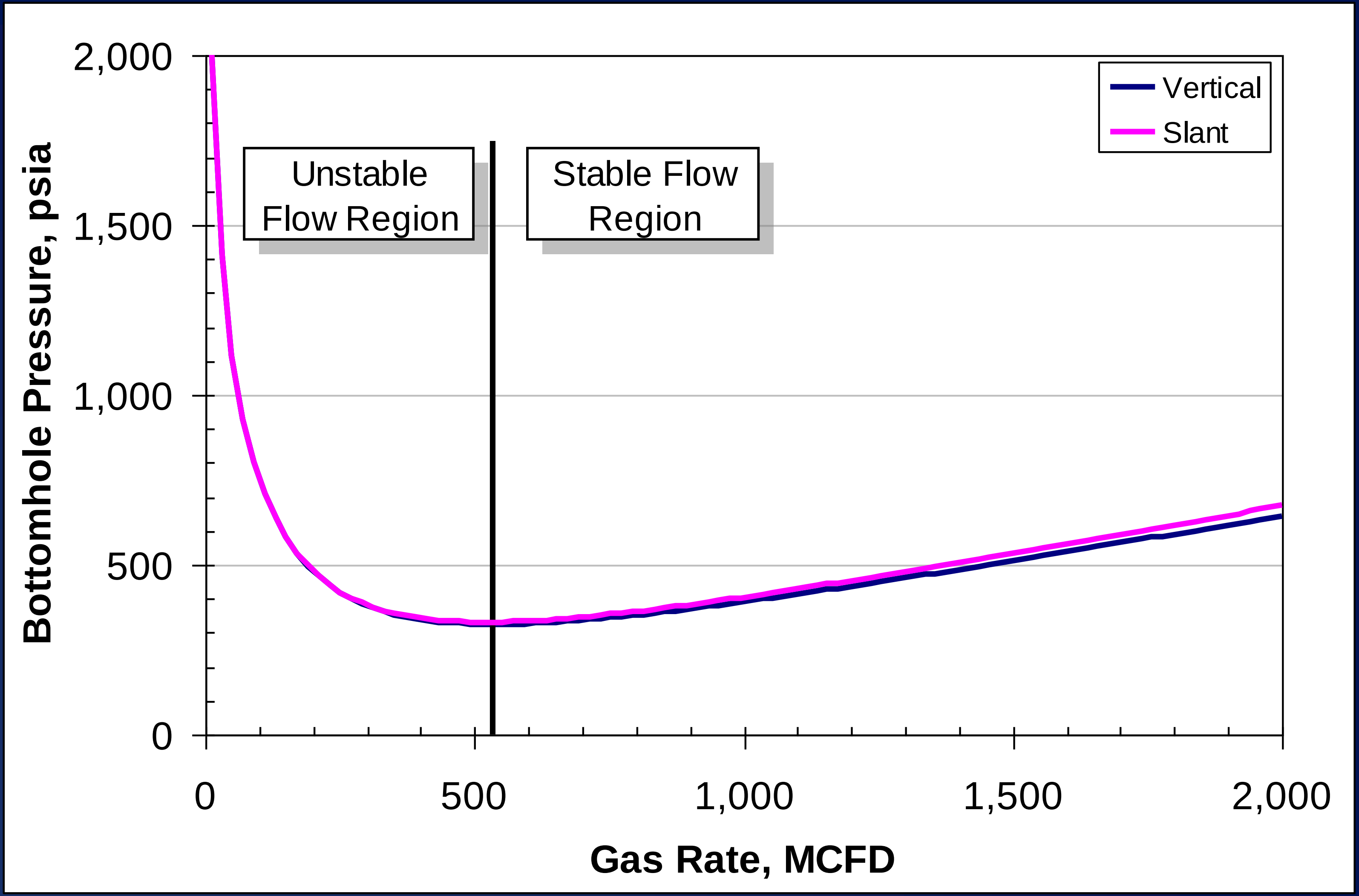
Vertical Flow Performance



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

ρ_g = gas phase density, lbm/ft^3

ρ_L = liquid phase density, lbm/ft^3

σ = surface tension, dynes/cm

$\boldsymbol{v_c}$ = critical velocity of liquid droplet, ft/sec

Turner Unloading Velocity

$$v_c = 1.5934\underbrace{\left[\frac{N_{we}}{30}\right]^{0.25}}_{\text{Turner Adjustment}}\left[\frac{\sigma(\rho_l-\rho_g)}{\rho_g^2}\right]^{0.25}\underbrace{\frac{[\sin(1.7(90-\theta))]^{0.38}}{0.740767}}_{\text{Belfroid et al SPE 115567 Angle Correction}}$$

where

ρ_g = gas phase density, lbm/ft^3

ρ_L = liquid phase density, lbm/ft^3

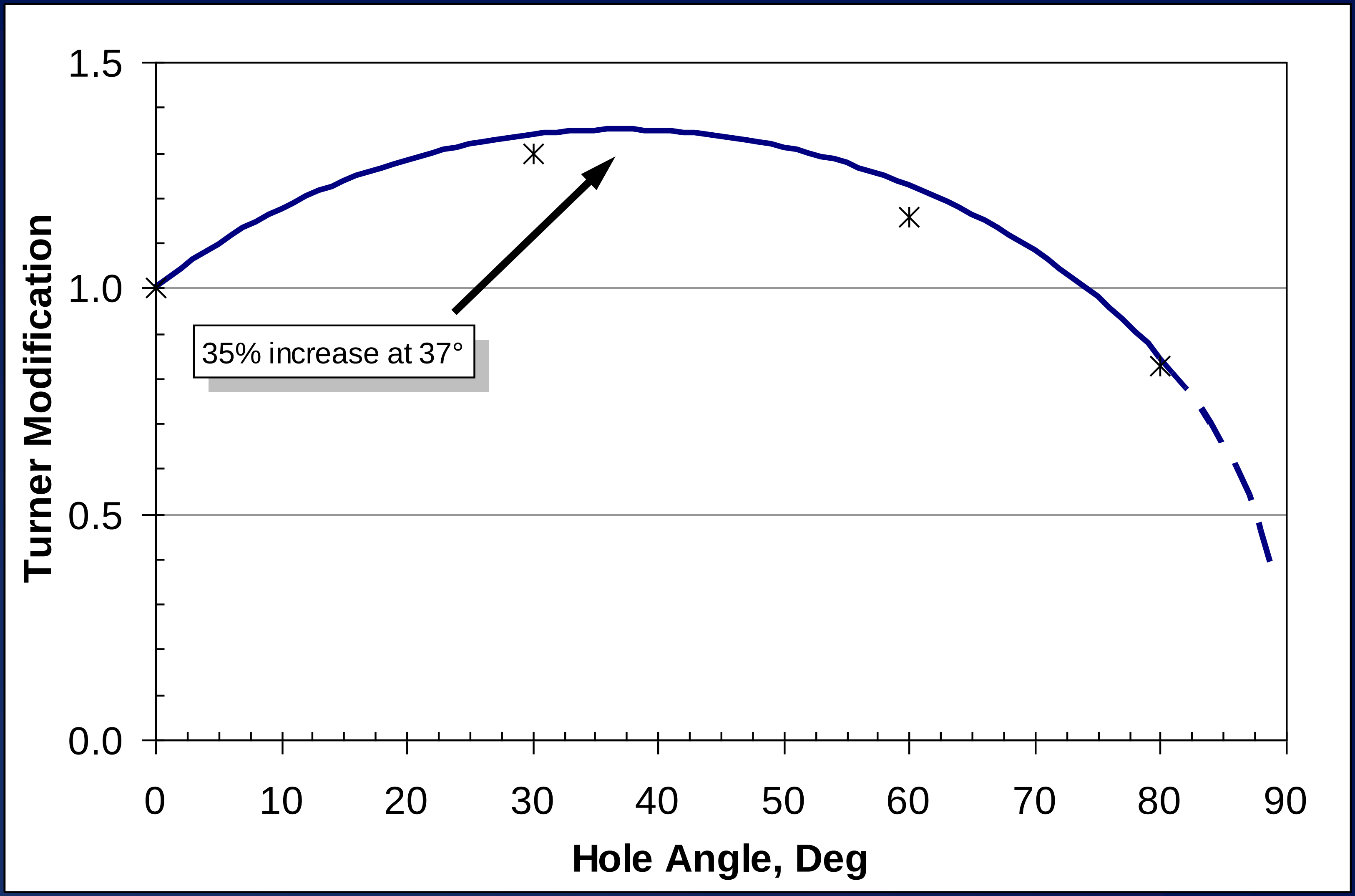
σ = surface tension, dynes/cm

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

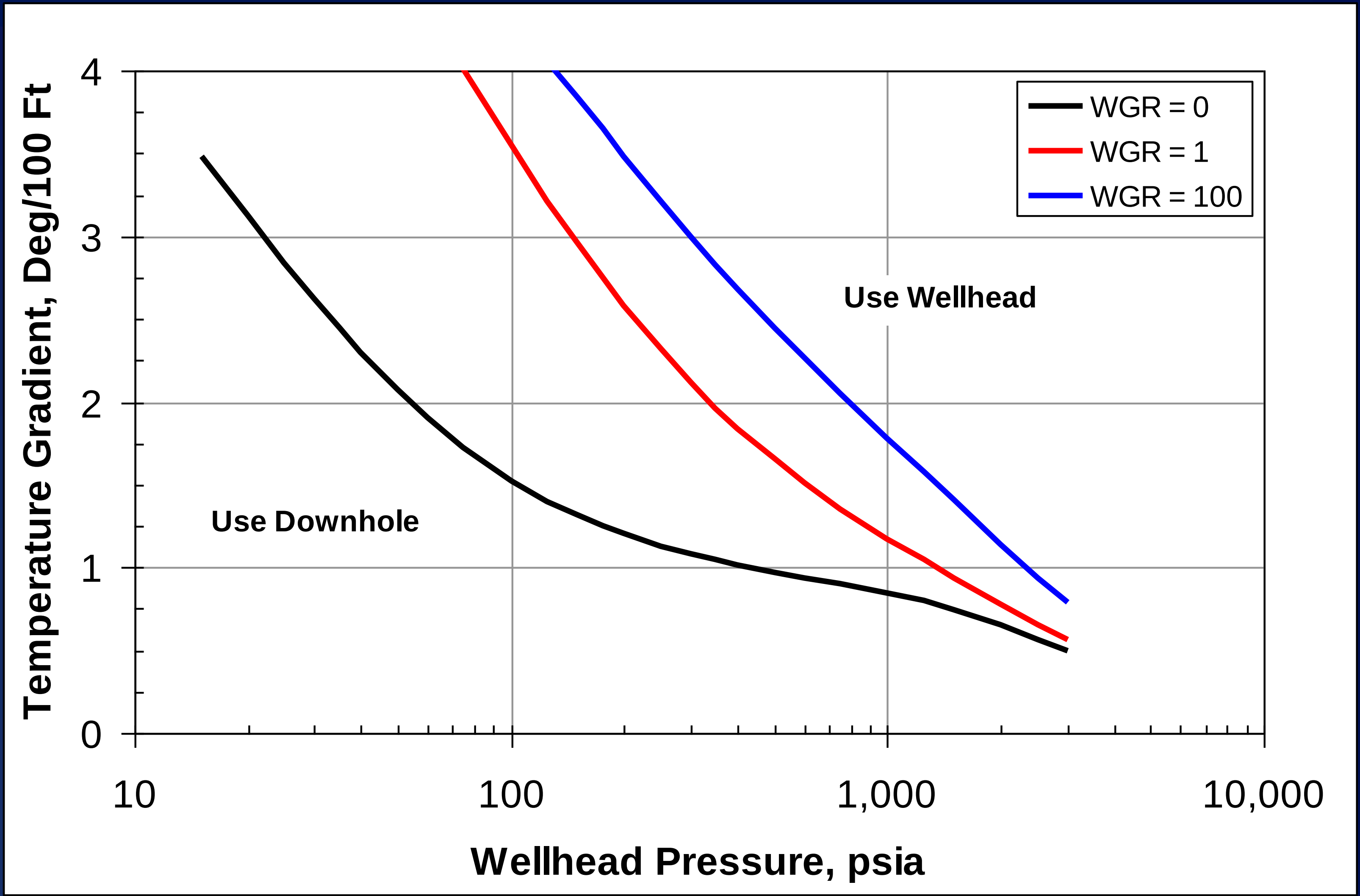
Θ = hole angle (Deg from vertical)

$\boldsymbol{v_c}$ = critical velocity of liquid droplet, ft/sec

Well Angle Modification to Turner



Evaluation Point

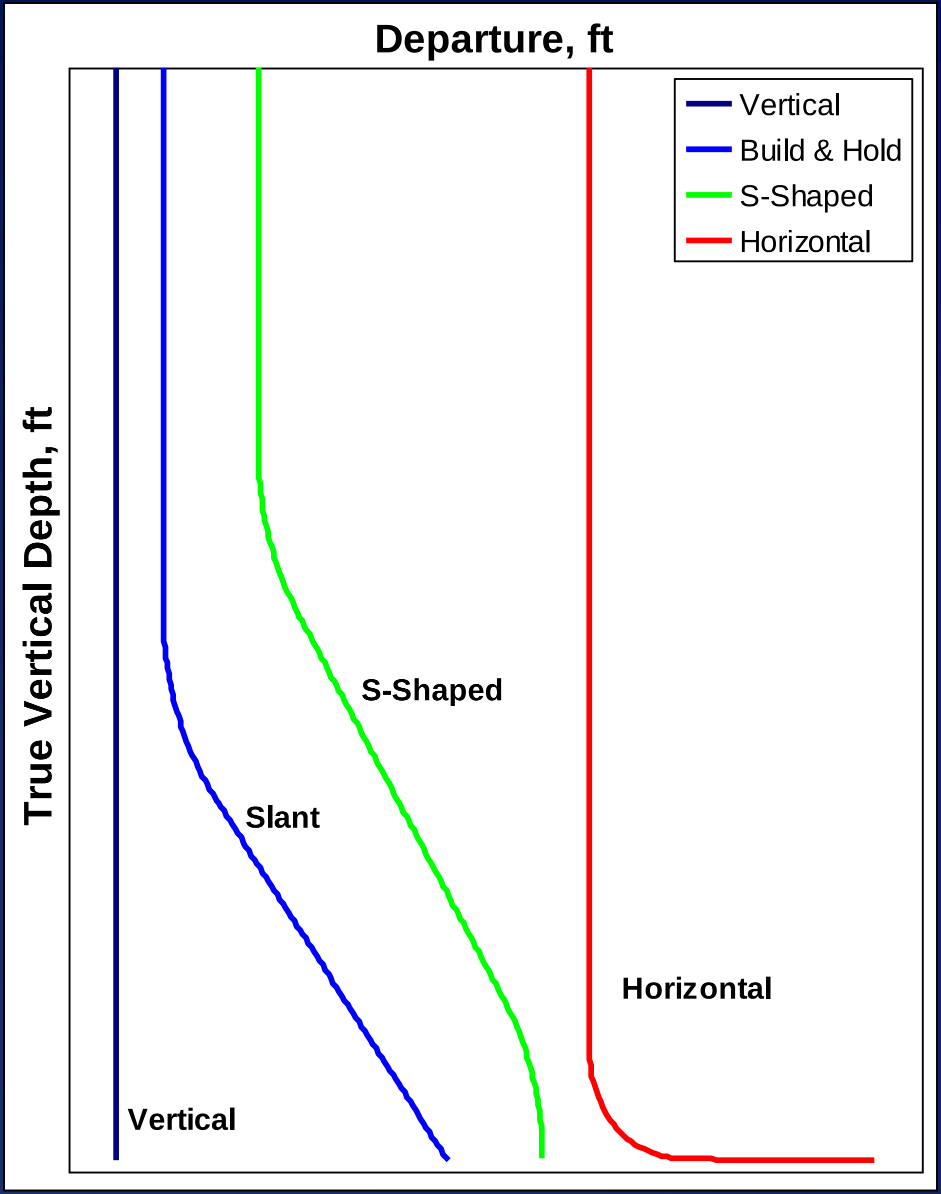


Dtbg = 2.441 in

γ_g = 0.65

SPE 120625

Assorted Well Profiles

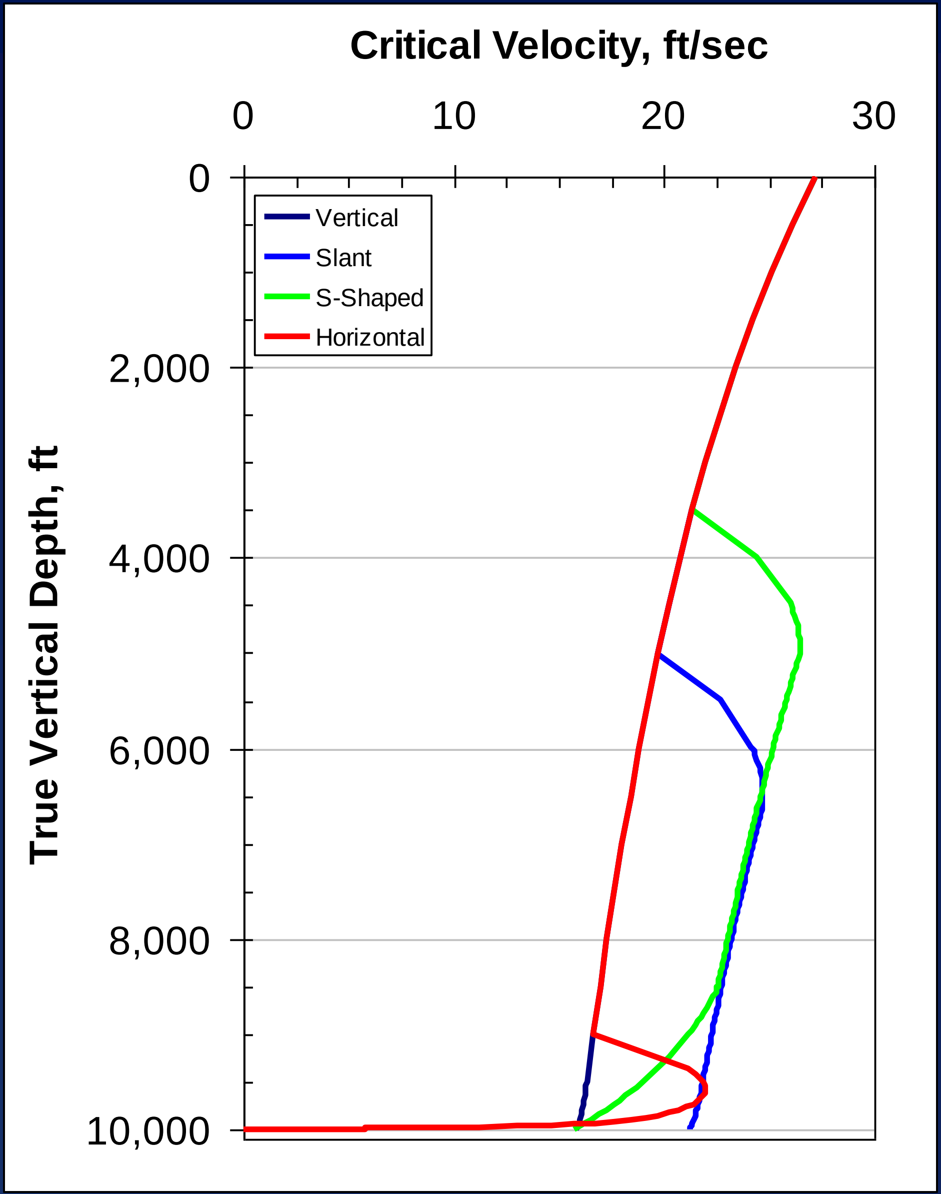


Complex Profiles

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

- Complexity increases velocity or rate to unload well

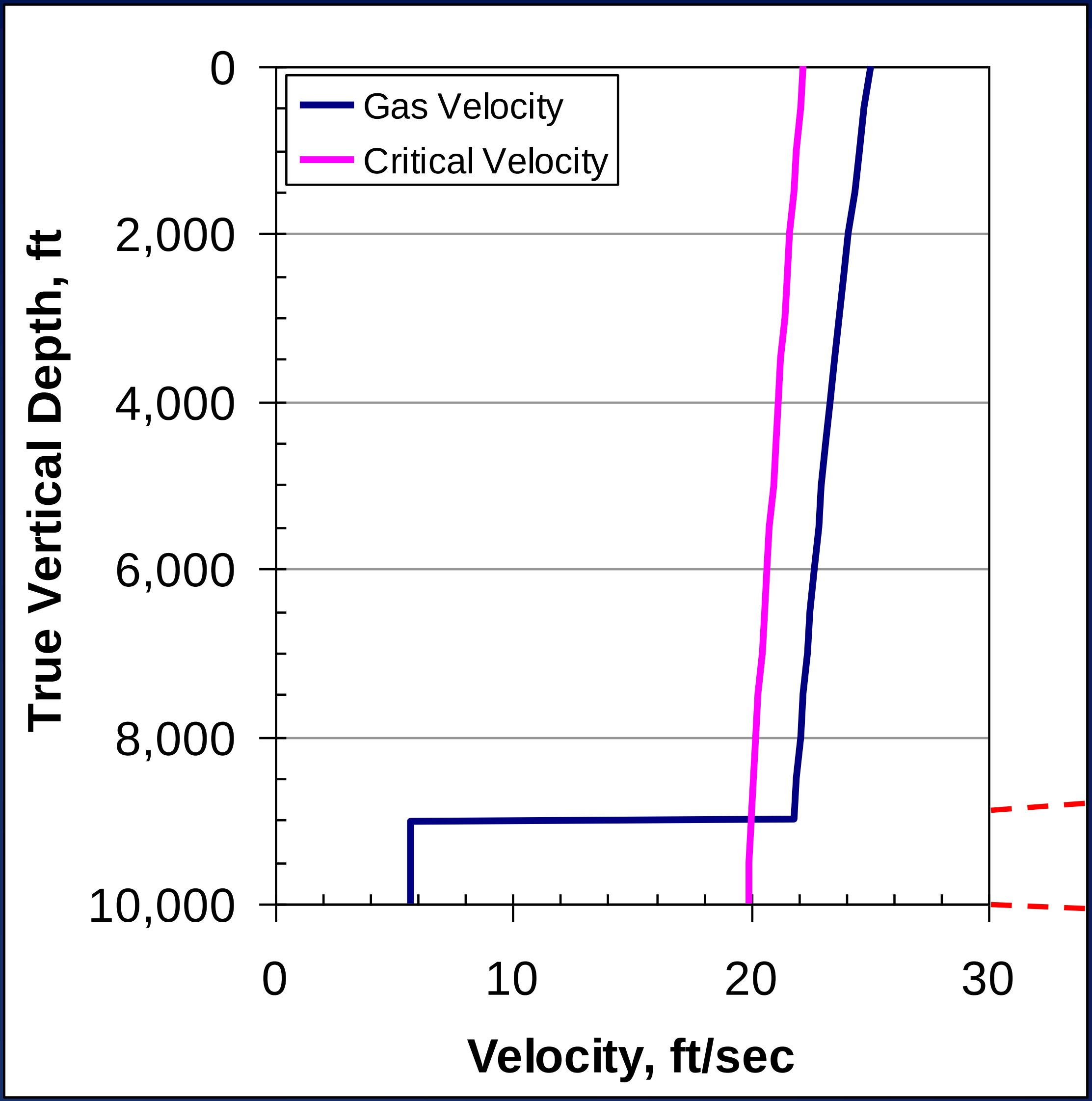
Example Critical Velocity Profiles

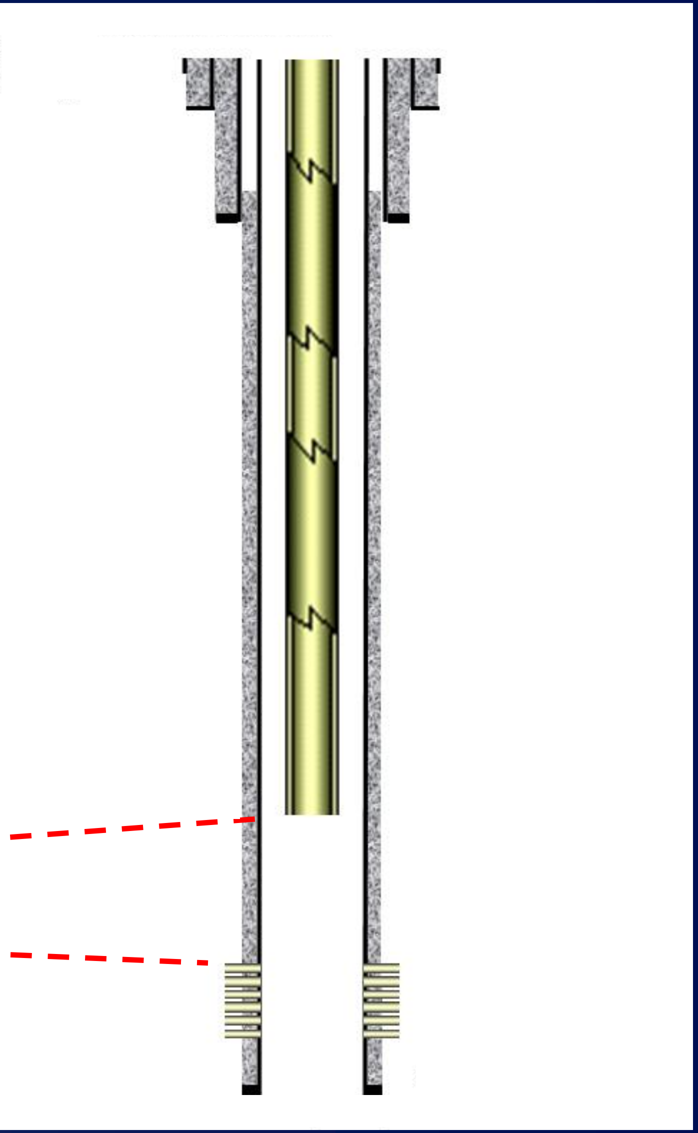


- Effects on critical velocity
  - Pressure
  - Temperature
  - PVT
    - Gas gravity
    - Water salinity
  - Hole Angle

Vertical Well Case

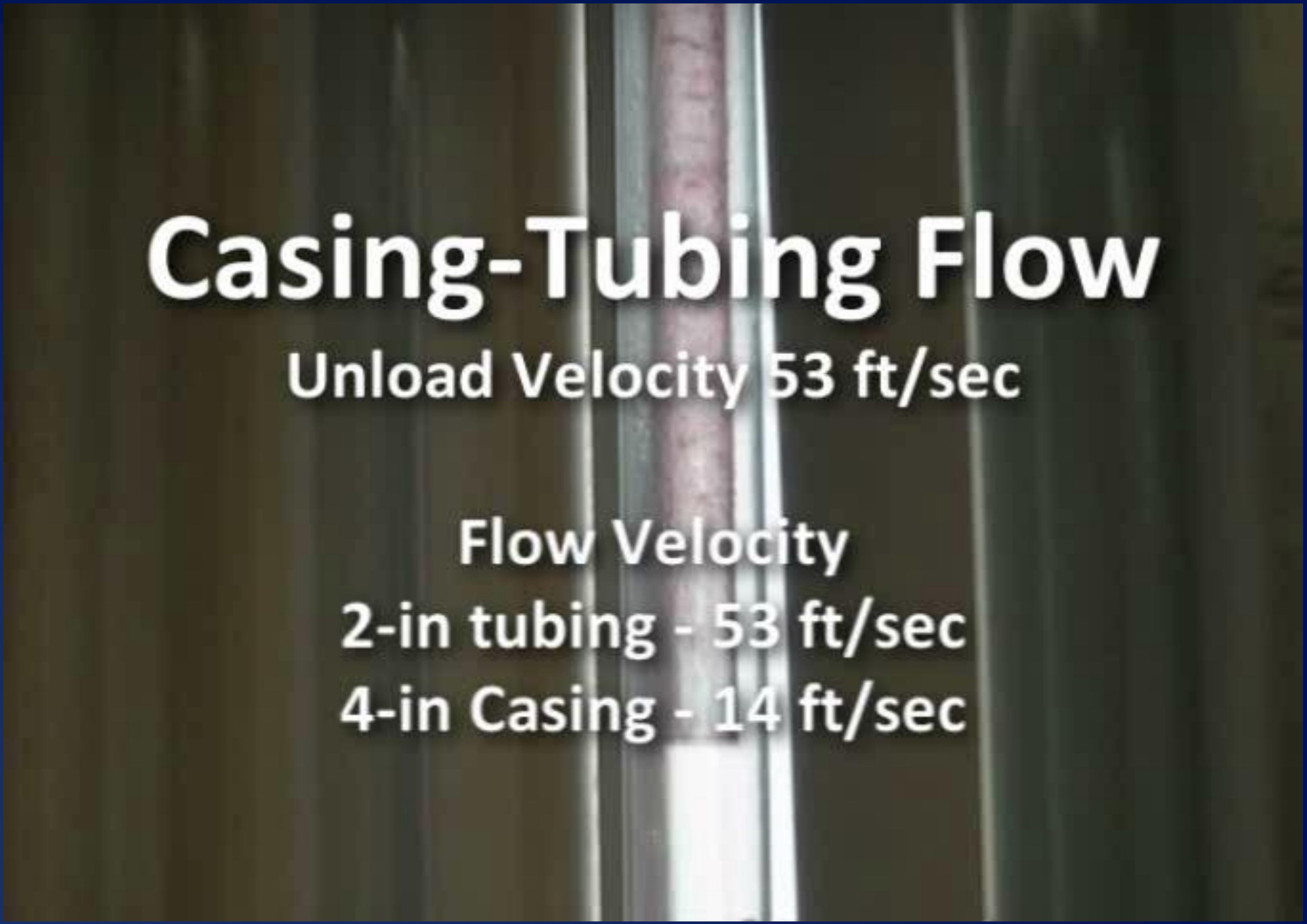
(Variable Tubing Size)





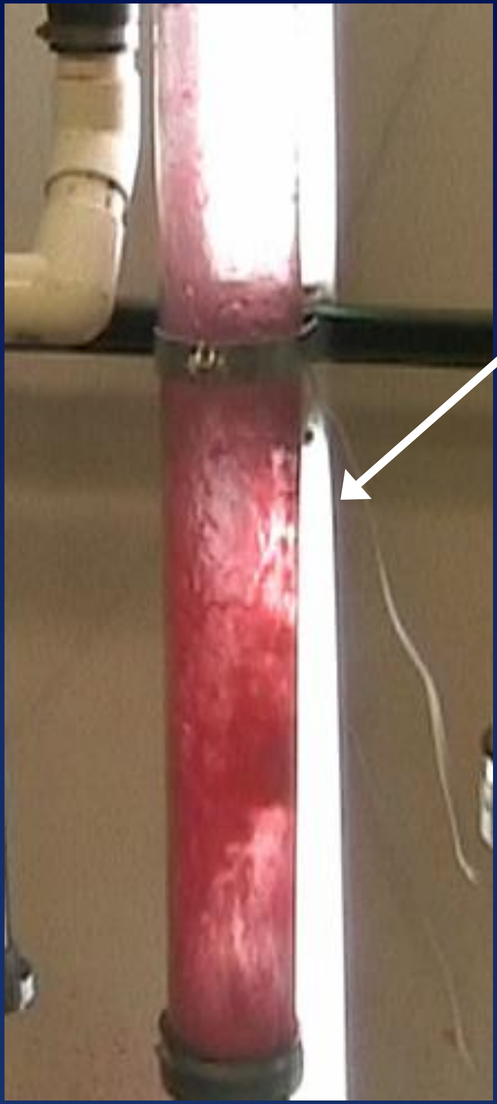
Liquid Loading

Bottom of Vertical Well



Liquid Loading

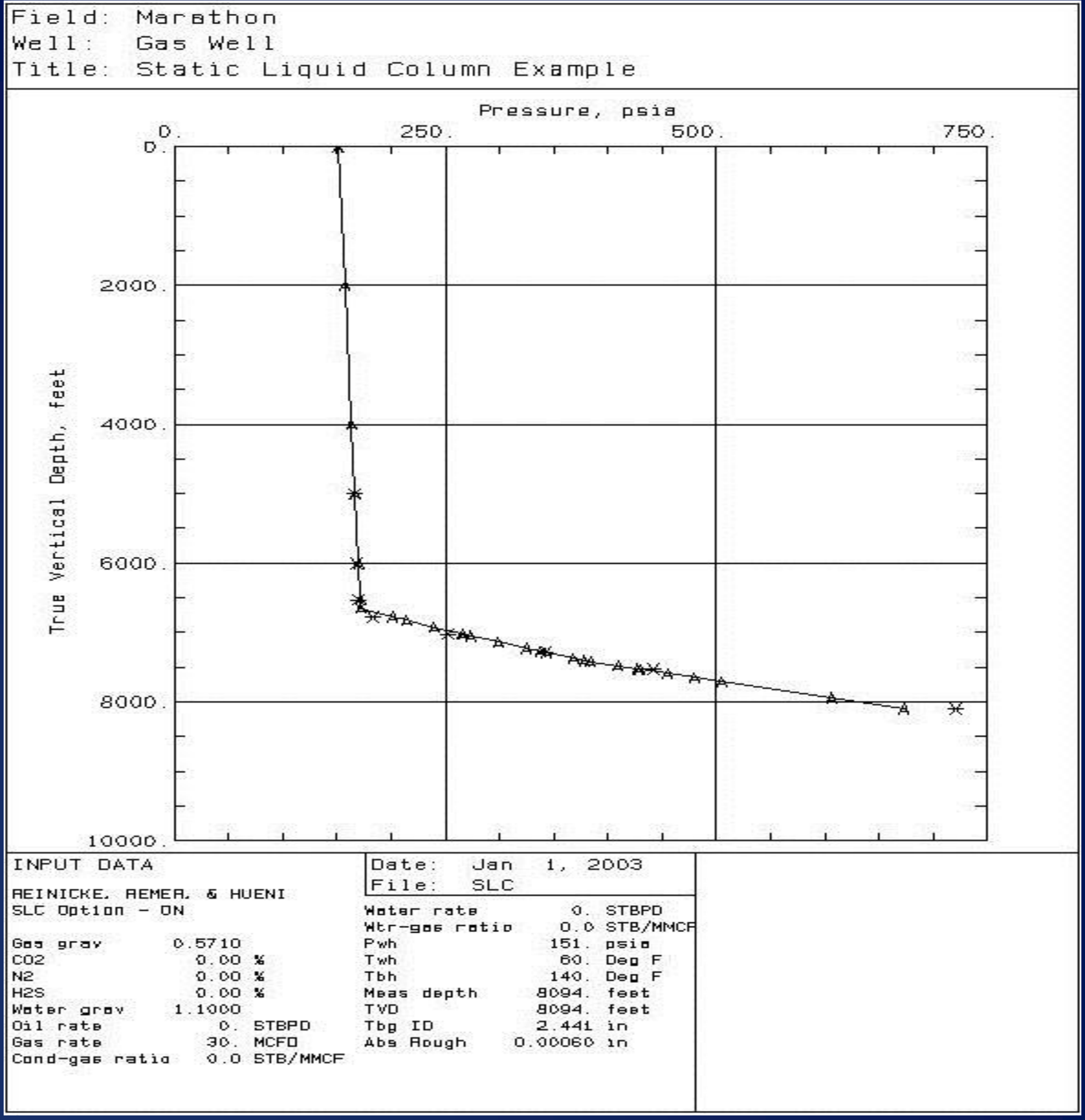
Bottom of Vertical Well



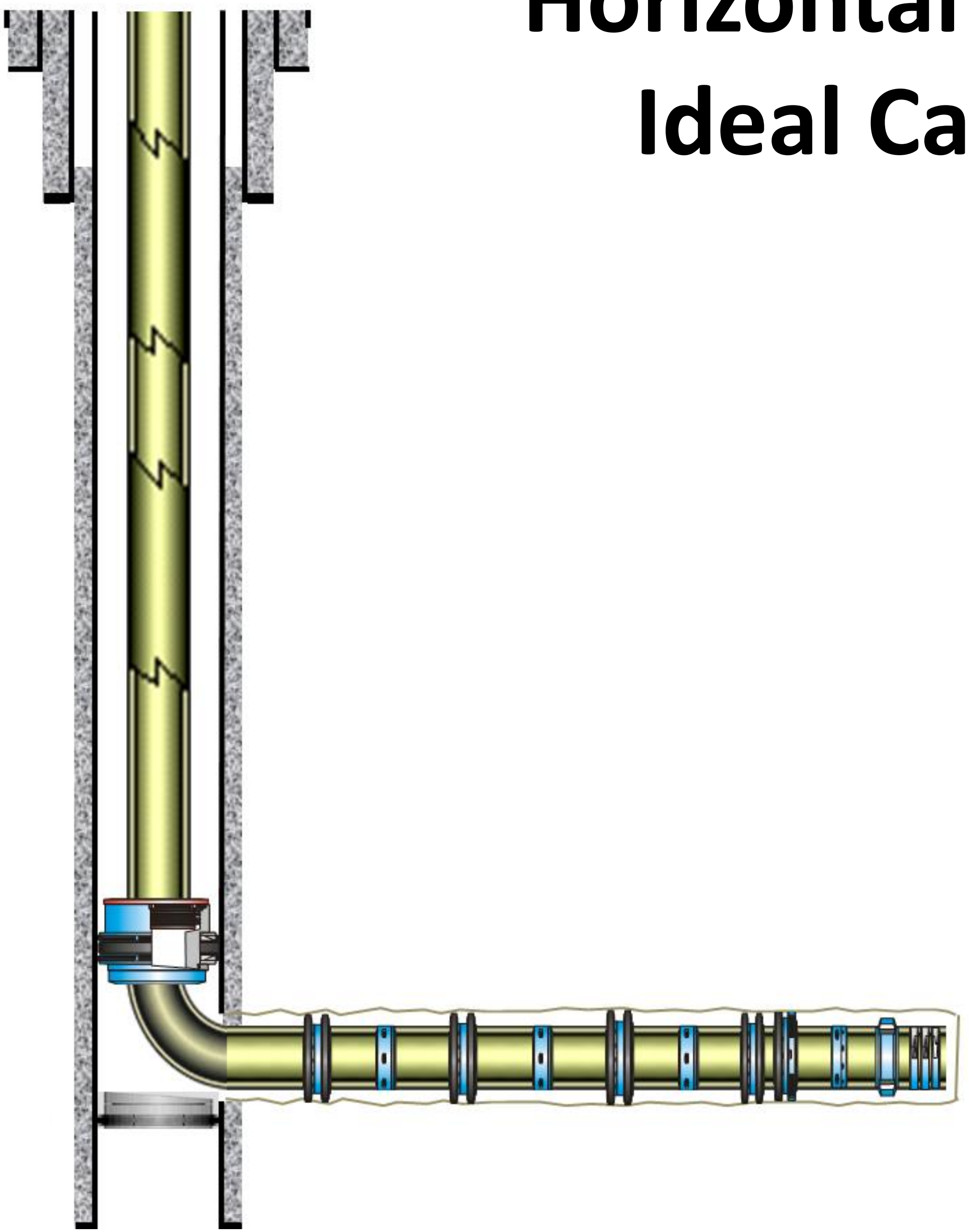
Gas-cut Liquid

Droplets variable size distribution

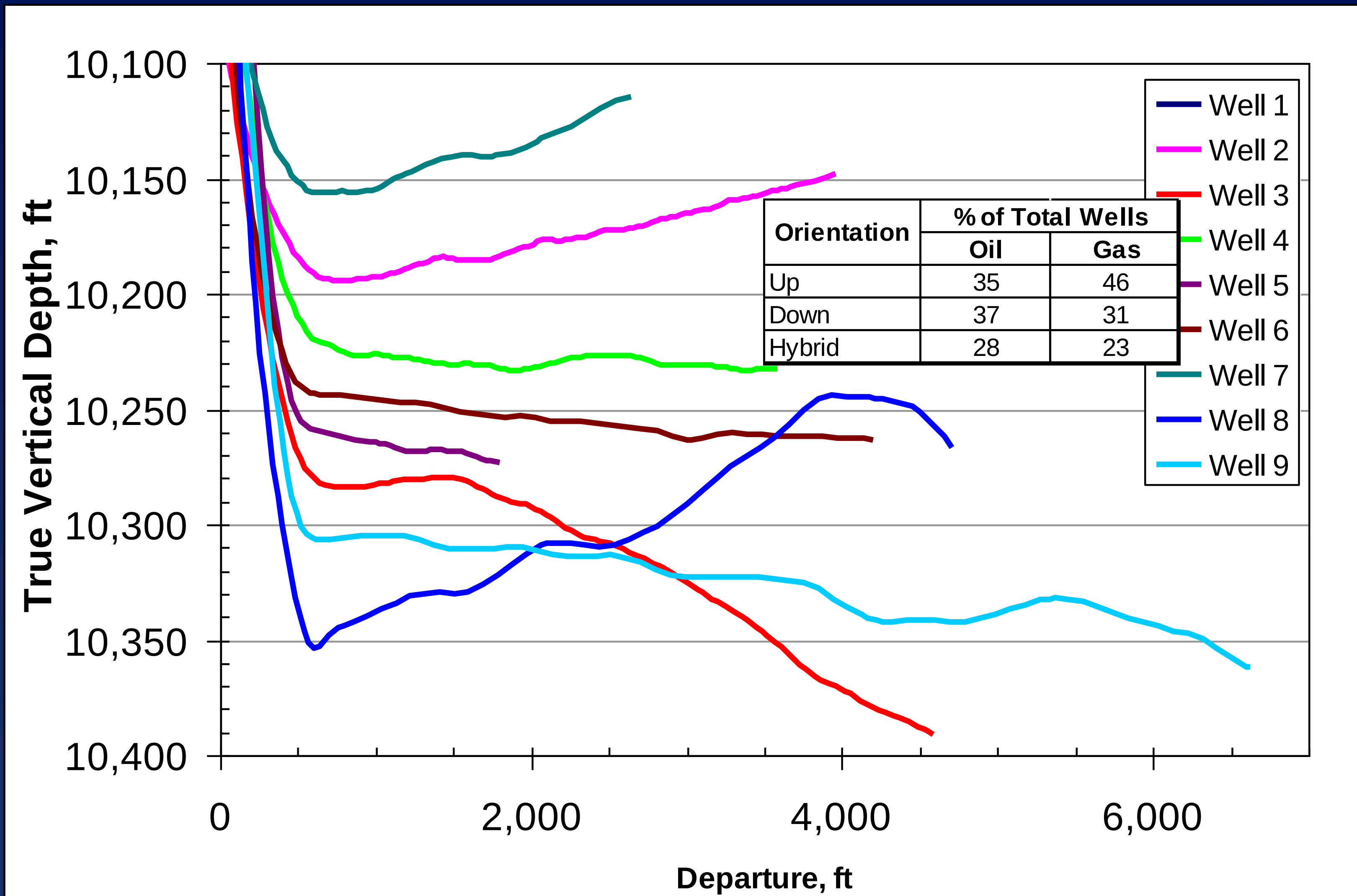
Static Liquid Column Pressure Profile



Horizontal Well
Ideal Case



Complex Horizontal Well Profiles



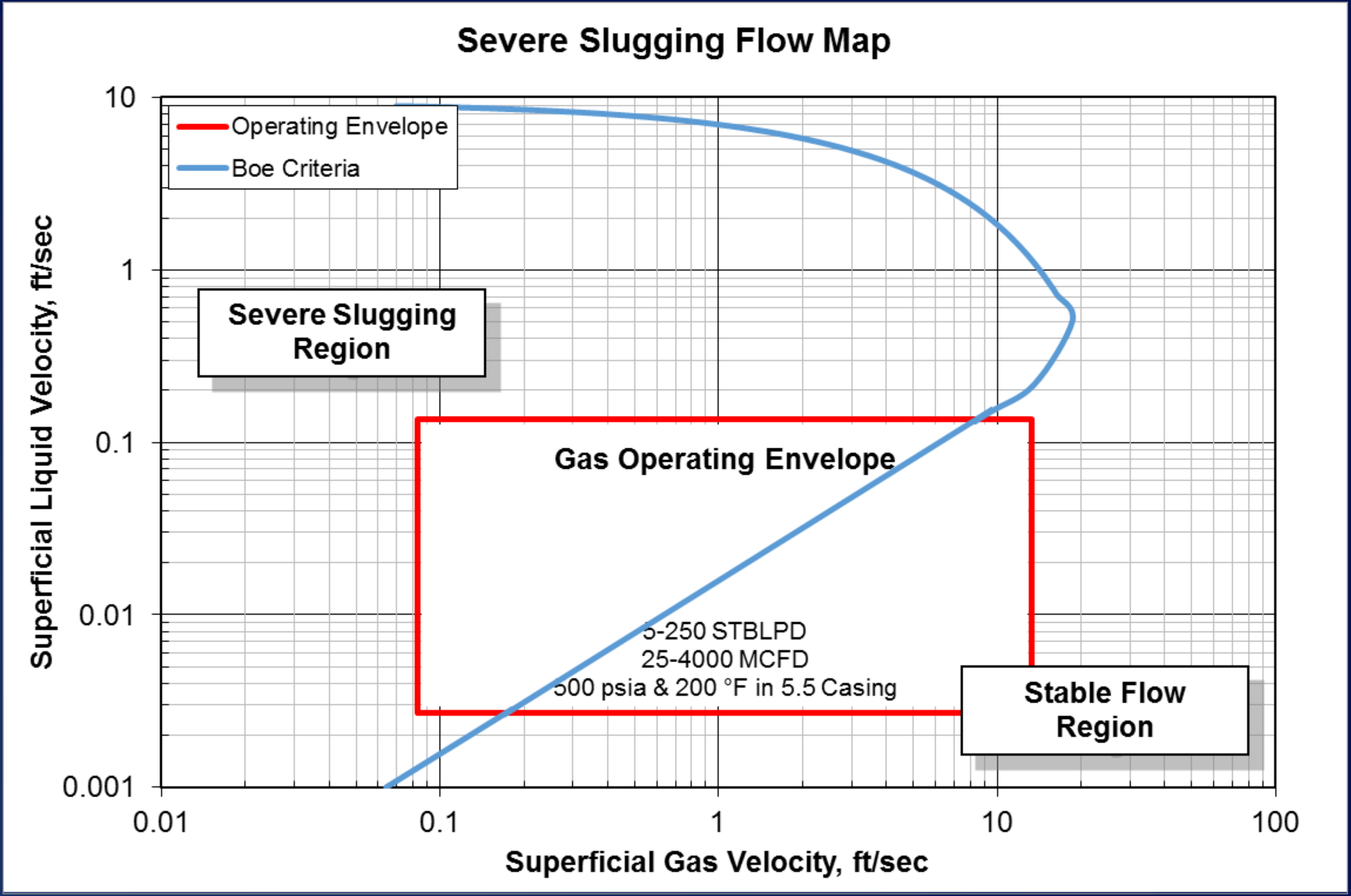
Orientation	% of Total Wells	
	Oil	Gas
Up	35	46
Down	37	31
Hybrid	28	23

Horizontal Well Profiles

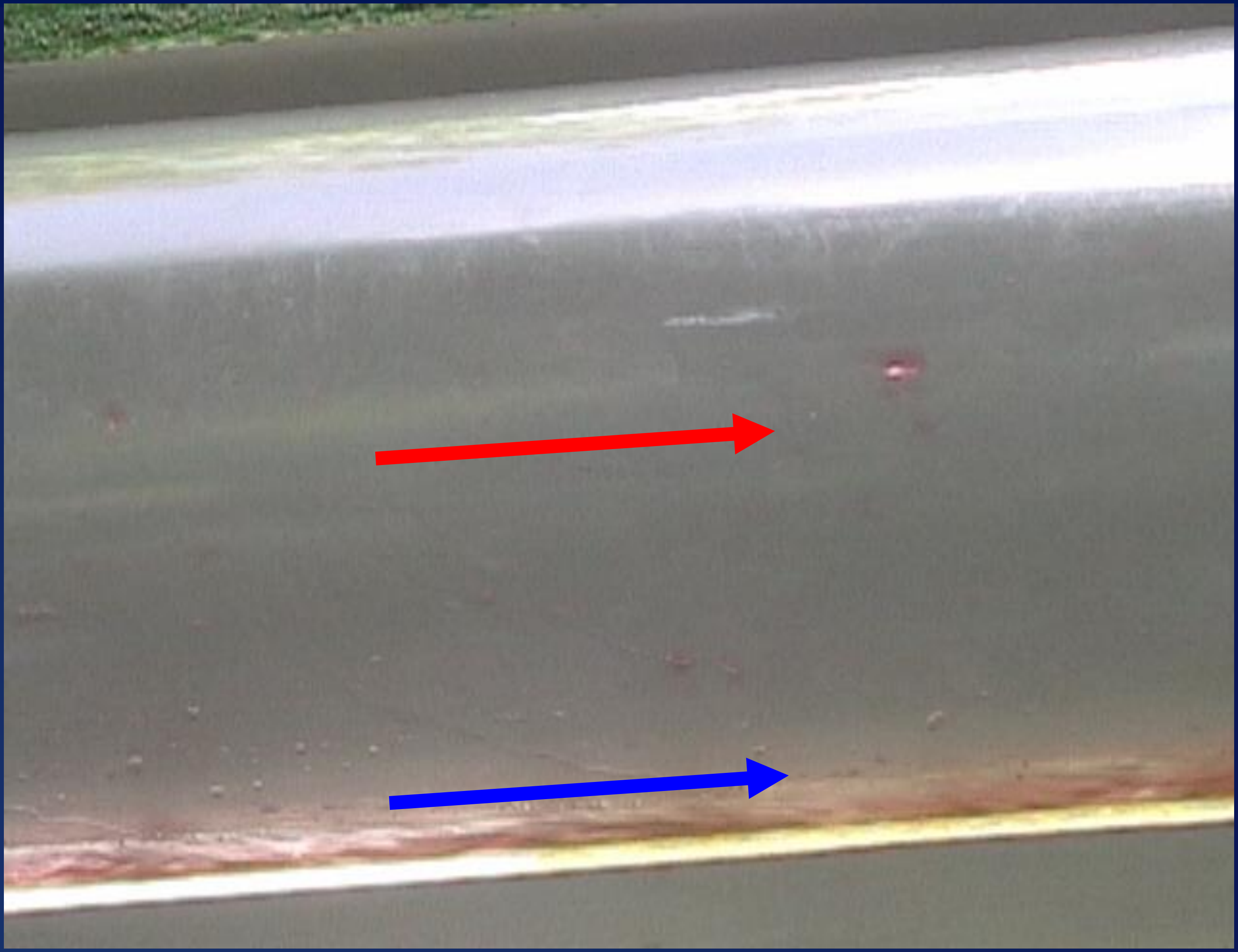
Fayetteville

Horizontal Well Geometry

Severe Slugging



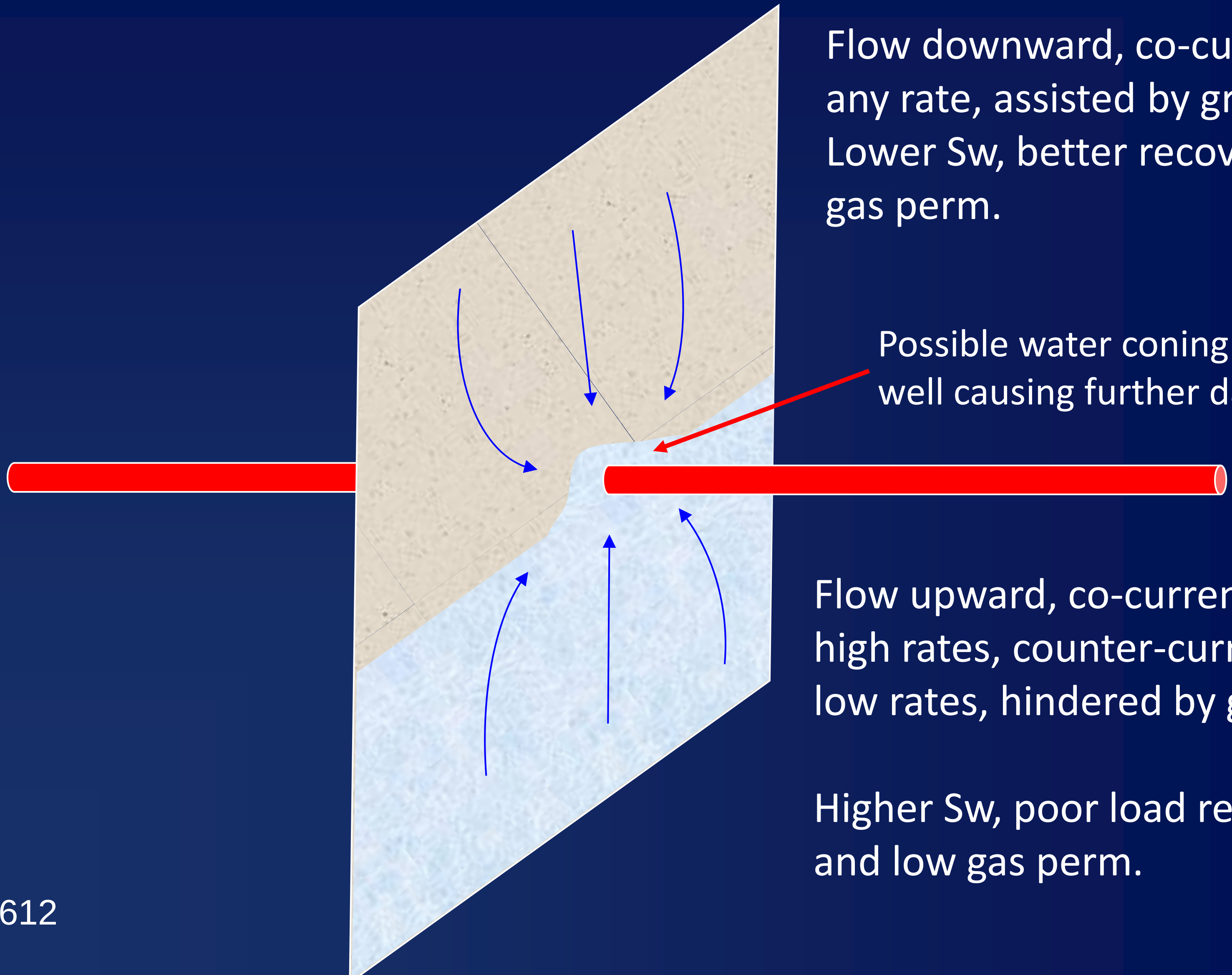
Liquid Loading at 86° from Vertical



4-in Pipe

Stratified flow pattern

Cleanup and Load Recovery in Vertical Fractures is Affected by Gravity, Viscous, and Capillary Forces



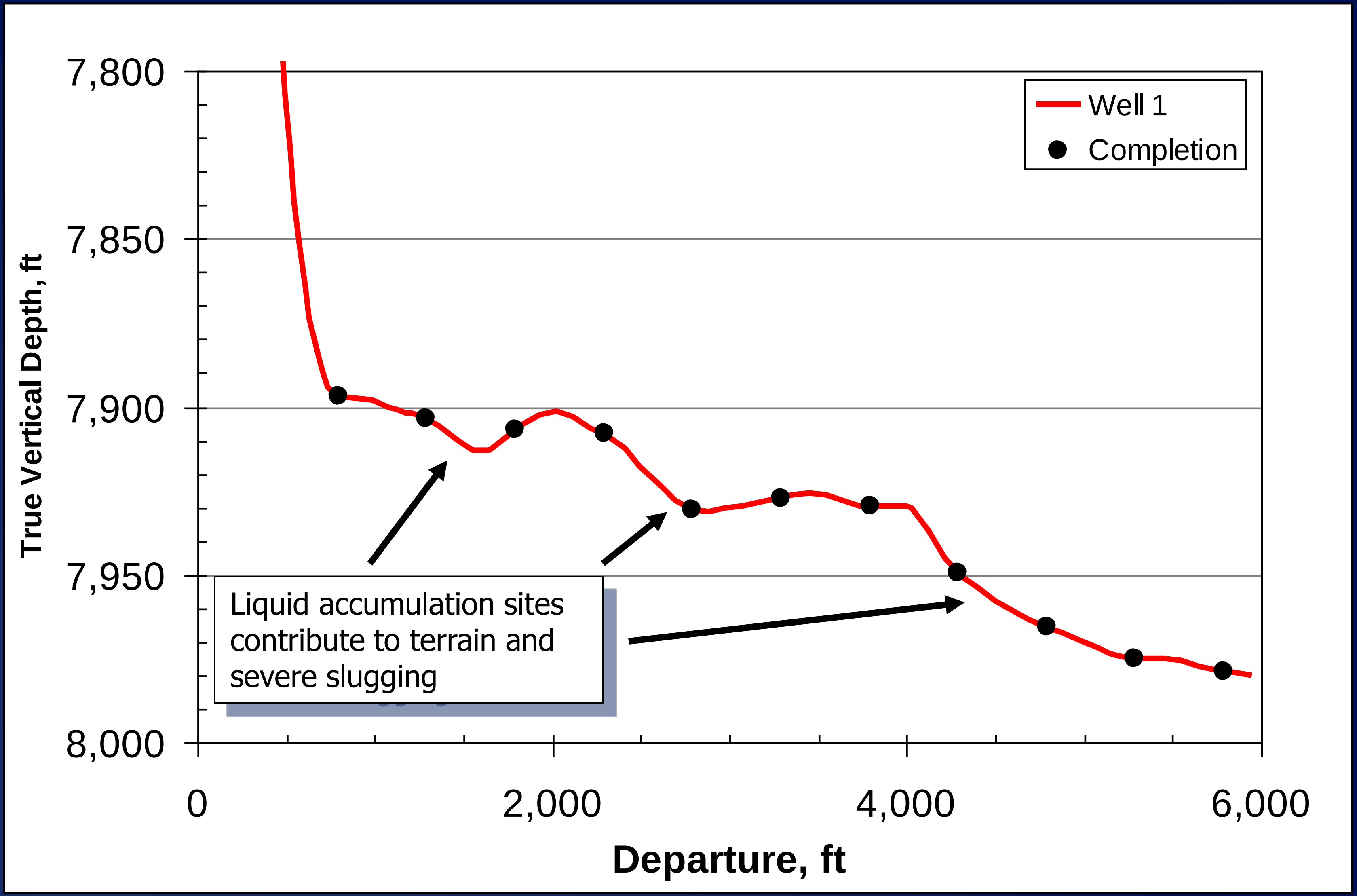
Flow downward, co-current at any rate, assisted by gravity. Lower Sw, better recovery and gas perm.

Possible water coning around well causing further damage?

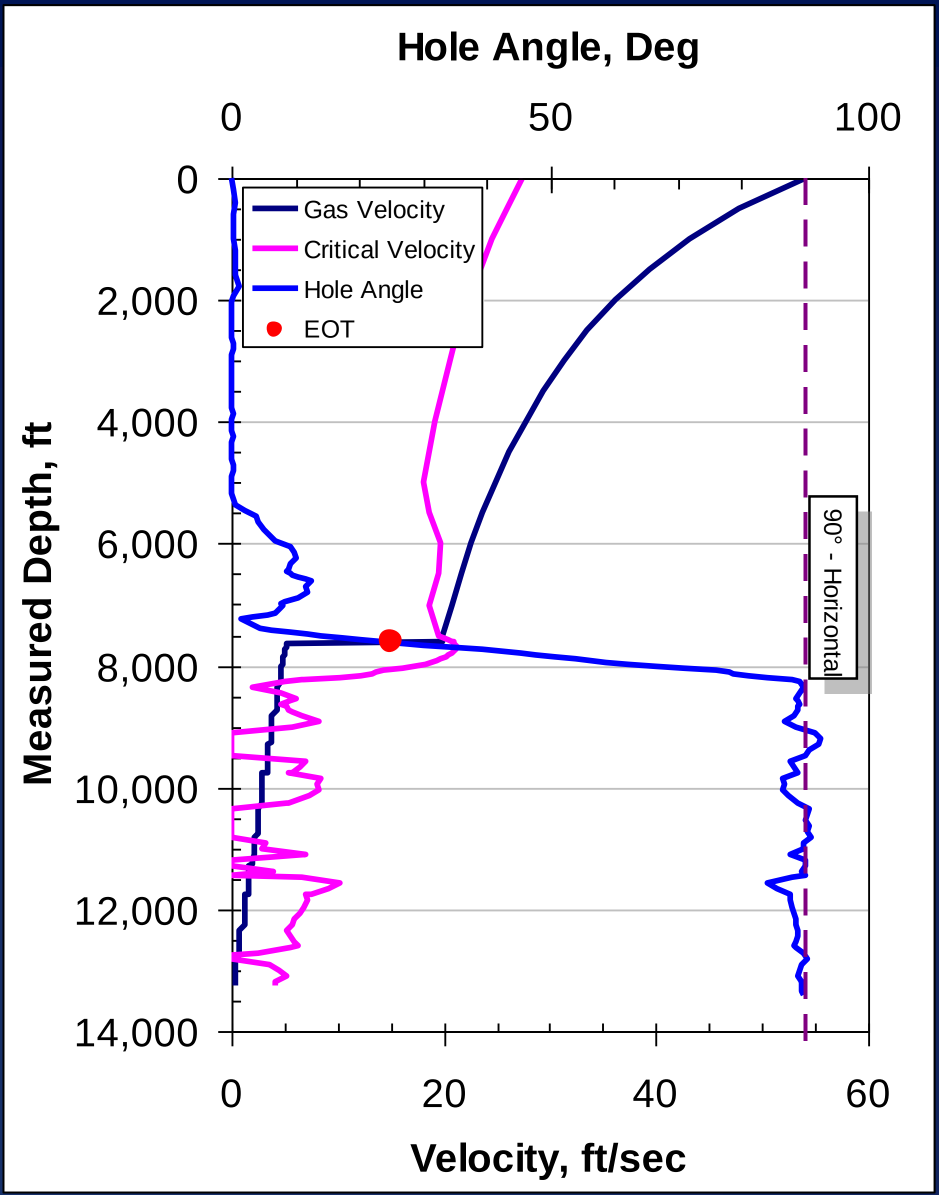
Flow upward, co-current at high rates, counter-current at low rates, hindered by gravity.

Higher Sw, poor load recovery, and low gas perm.

Example Horizontal Well

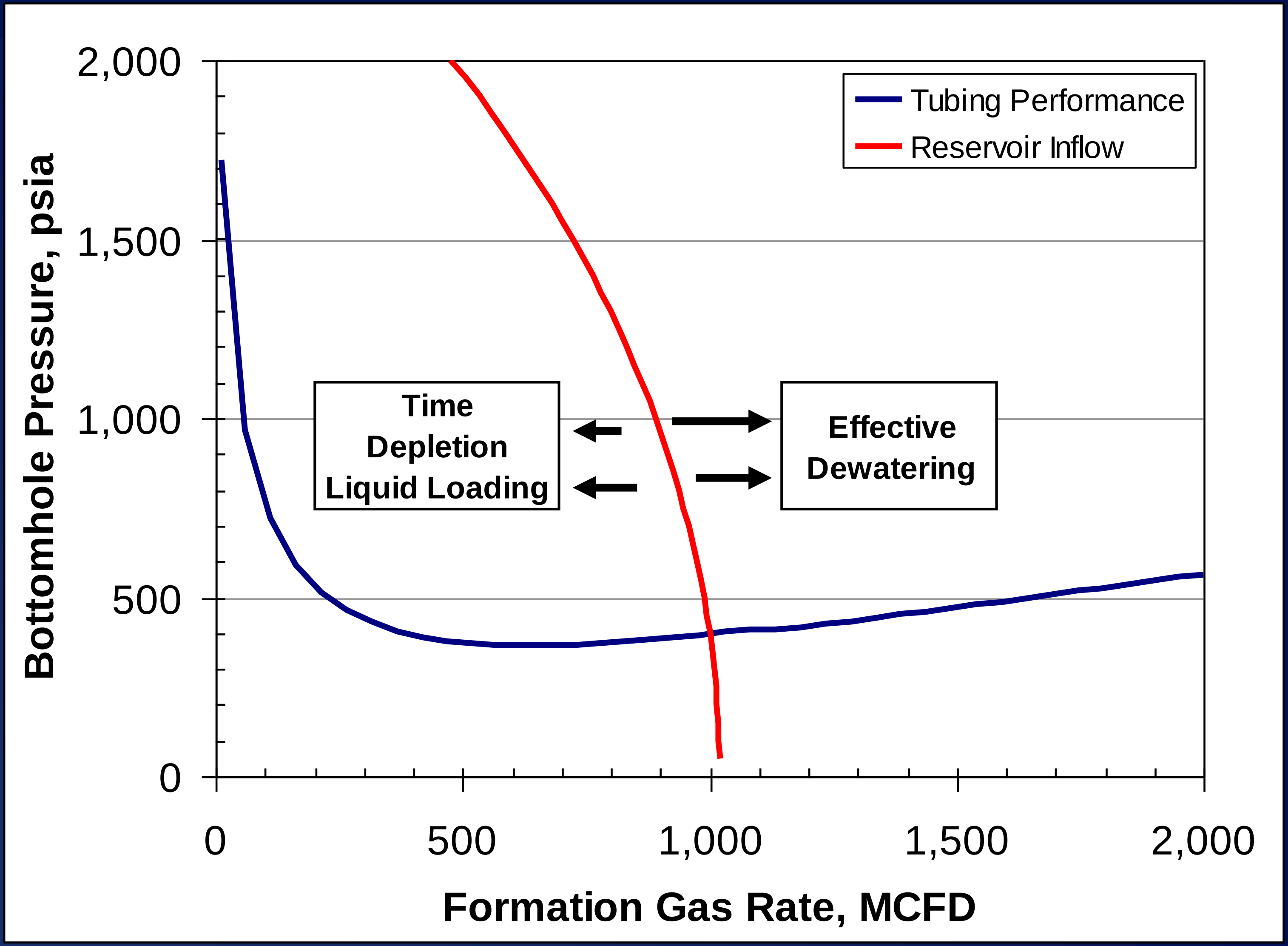


Example Horizontal Well

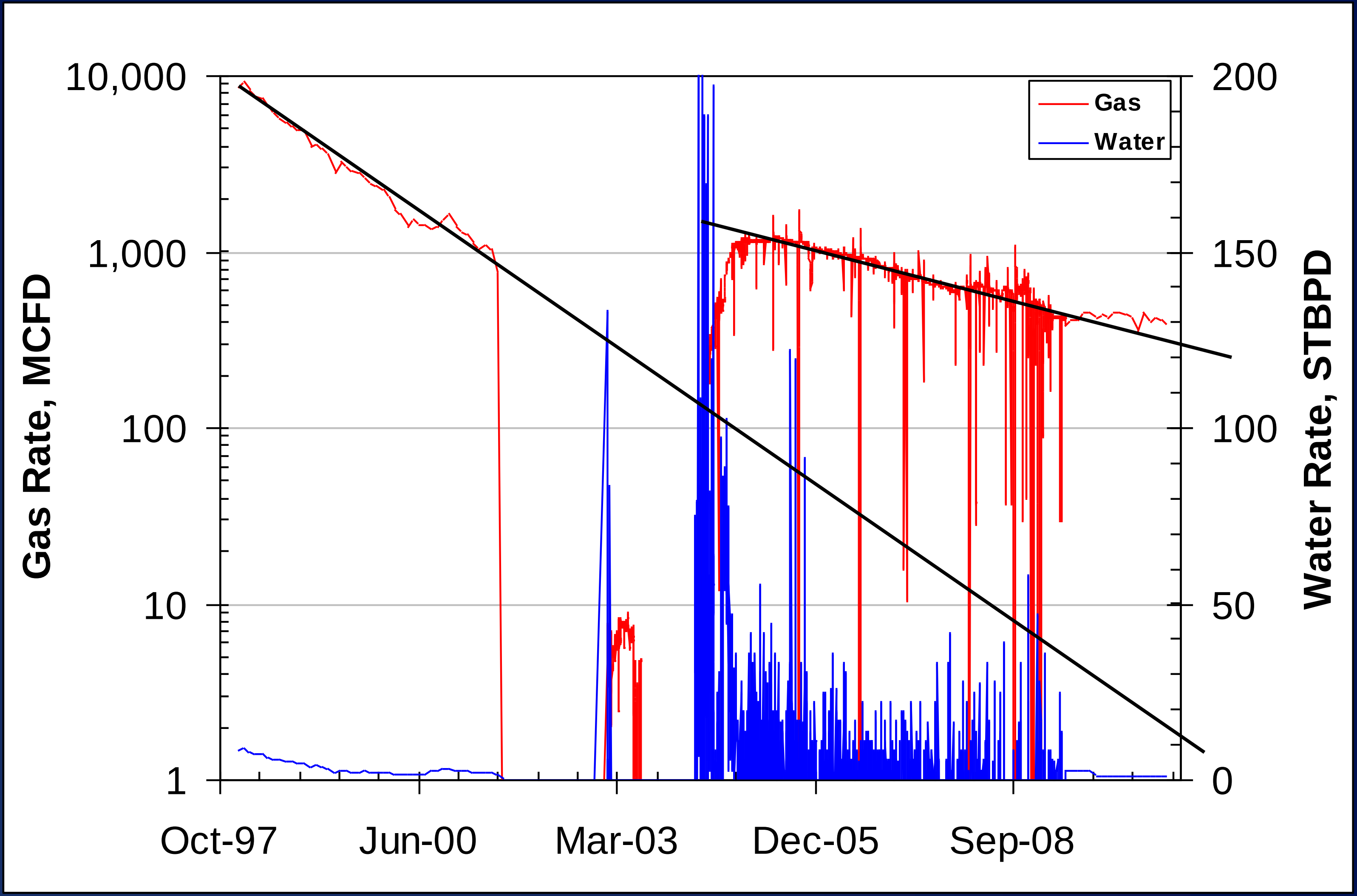


- Velocity profile
- Gas velocity
  - Comparison with critical velocity
- EOT at 25°
  - Shallow
  - Slugging in curve
  - Slugging in horizontal

Factors Affecting Rate-Time Decline



Example of Successful Deliquification Program



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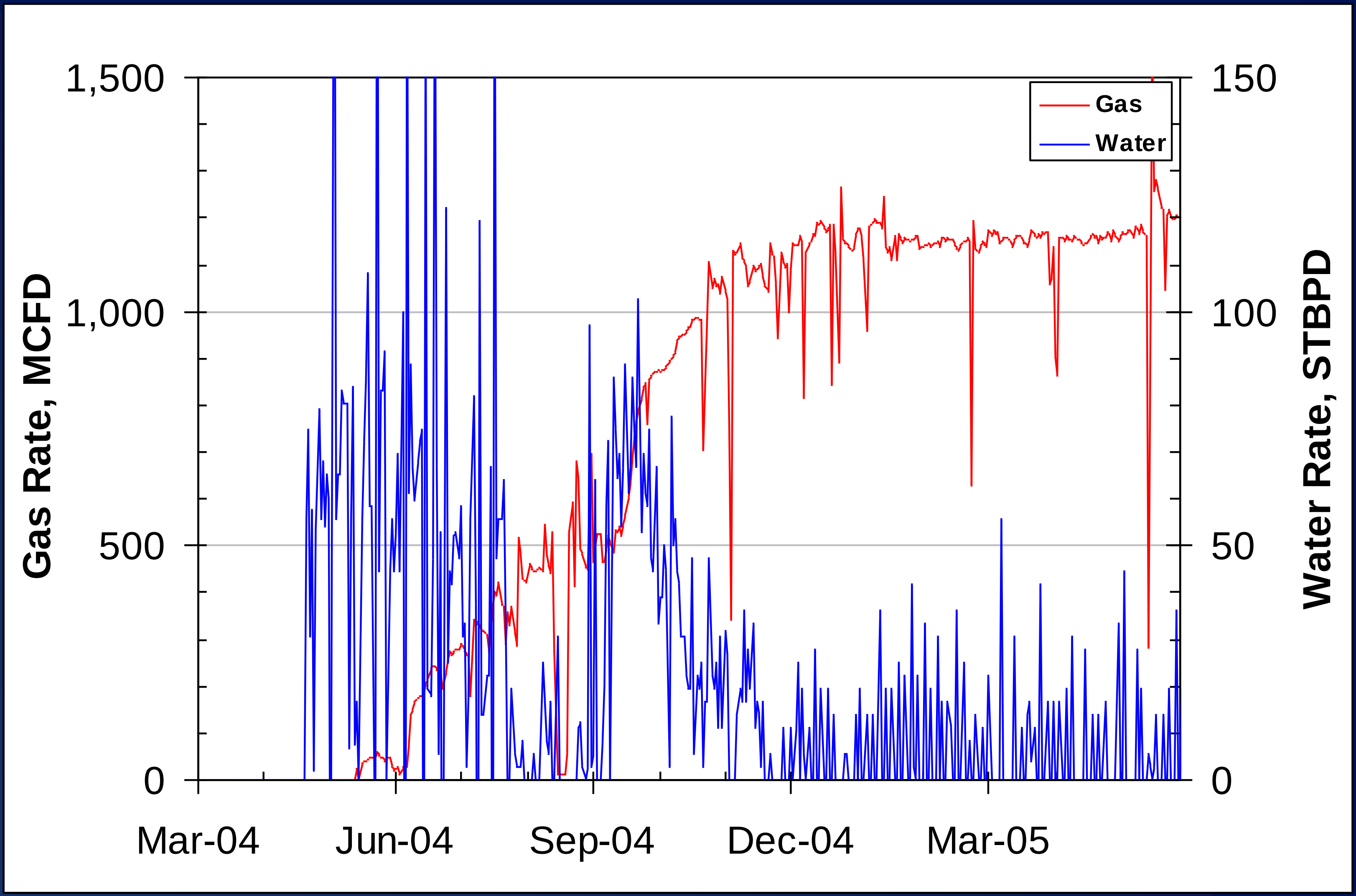

Possible Solutions

- 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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