What is your job title?

- Engineer
- Geologist
- Geophysicist
- Consultant
- Educator

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What geographic region are you from?

- North America
- South America
- Africa
- Middle East
- Europe
- Asia
- Other

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Presentation Outline

- Introduction
- Liquid Loading: Cycle & Its Impact
- Challenges Of Deliquifying Laterals
- State-of-the-art: Deliquifying Laterals
- Lift Life Cycle Planning
- Q&A

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Who is your employer?

- E&P Company
- NOC
- Government
- Academia
- Consultant
- Non-governmental Organization
- Environmental Organization

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How many years of experience do you have?

- 0-5
- 6-10
- 11-15
- 16-20
- 20+

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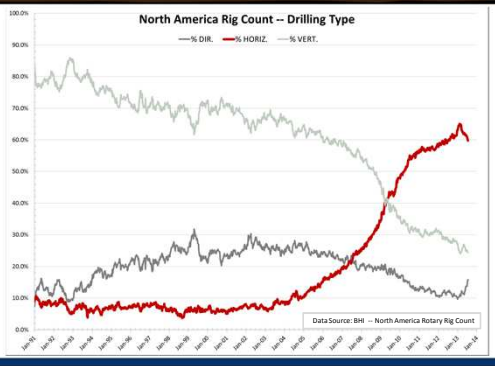

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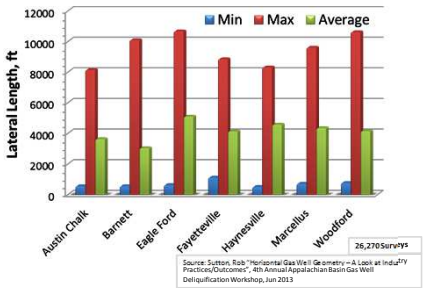
Horizontal Gas Well Laterals in Shale Plays



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The gas well liquid loading is primarily a function of:

- Liquid viscosity
- Bottom Hole Temperature
- Internal Tubular Roughness
- Gas Velocity

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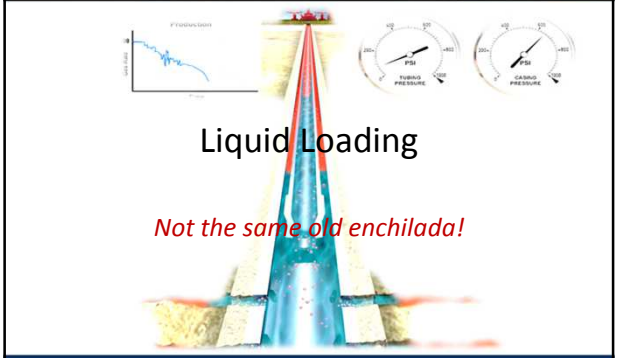

Liquid Loading

Not the same old enchilada!

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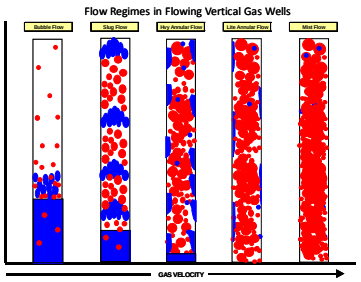
Liquid "Loading" in Vertical Wells is understood and is mature



$Loading\ rate = f\{gas\ velocity\}$

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Gas Well Production Fundamentals – It's all about *VELOCITY*

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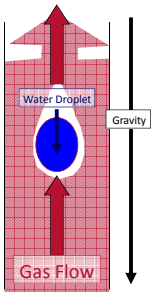
Liquid Loading: Turner Equation

- Calculates flow velocity that keeps "liquid drop" stationary in flow stream; calculate critical velocity necessary to maintain drag force.
- Coleman equation for Lower pressures P < 1,000 psi



Critical Velocity Equation

$$V_c = 1.593 \frac{\sigma^{1/4}(\rho_{Liquid}-\rho_{Gas})^{1/4}}{\rho_{Gas}^{1/2}}$$

Critical Flow Rate Equation

$$Q_{(MMCFPD)} = \frac{3.06\ P\ V_c\ A}{T\ Z}$$

P	Flowing Tubing Pressure
V_c	Critical Velocity
A	X-Area Tubular Flow Path
T	Flowing Temp °R
Z	Z Factor

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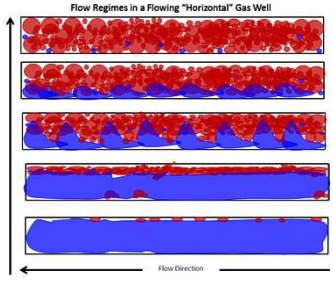
Liquid "Loading" in Horizontal Wells is becoming understood . Solutions are emerging



What is the critical velocity in a "horizontal" well that is not actually horizontal?

$$Loading\ rate = f\{gas\ velocity + well\ geometry\}$$

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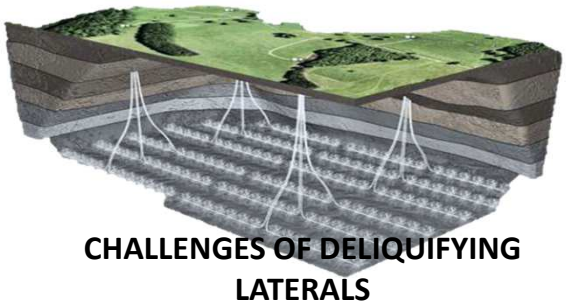


CHALLENGES OF DELIQUIFYING LATERALS

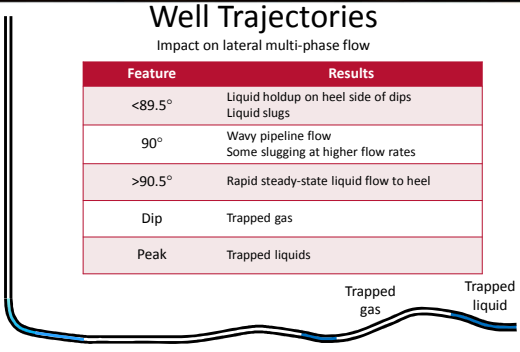
Does lateral trajectory affect wellbore loading in a horizontal well?

- Yes
- No
- Probably

Well Trajectories

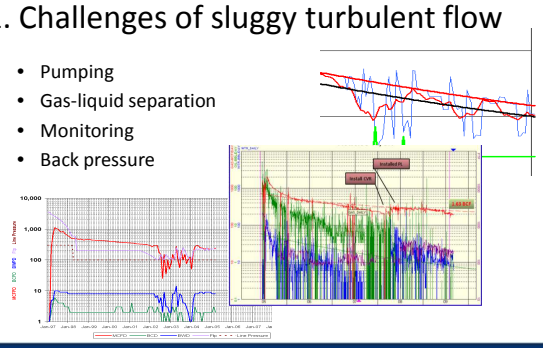
Impact on lateral multi-phase flow

Feature	Results
<89.5°	Liquid holdup on heel side of dips Liquid slugs
90°	Wavy pipeline flow Some slugging at higher flow rates
>90.5°	Rapid steady-state liquid flow to heel
Dip	Trapped gas
Peak	Trapped liquids



1. Challenges of sluggy turbulent flow

- Pumping
- Gas-liquid separation
- Monitoring
- Back pressure



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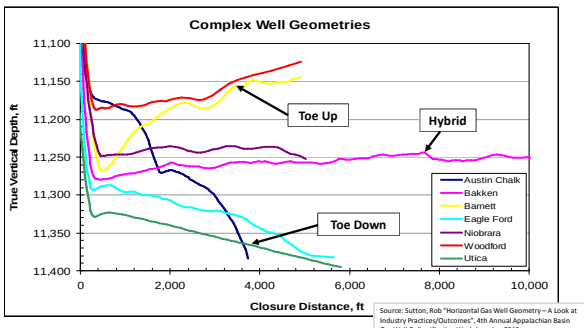

Source: Sutton, Rob "Horizontal Gas Well Geometry – A Look at Industry Practices/Outcomes", 4th Annual Appalachian Basin Gas Well Deliquification Workshop, Jun 2013

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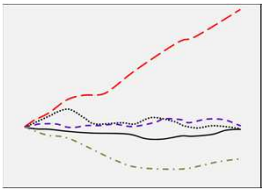
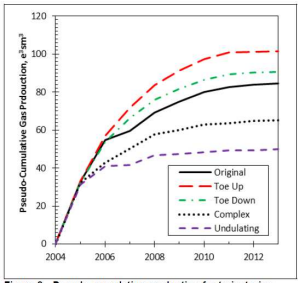
2. Impact of well geometry on EUR



Results based on simulations in a tight gas field.



Source: Jackson *et al.*, "Investigation of Liquid Loading in Tight Gas Horizontal Wells With a Transient Multiphase Flow Simulator" SPE 149477

Figure 8—Pseudo-cumulative production for trajectories.

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Counterpoint… is the problem real?

Based on the statistical studies, observations by Sutton:

- "Data from mature plays suggest that long term performance is not influenced by lateral orientation"
- "Completion philosophy may mask any benefits from different lateral orientation"
- "Further work is required by the industry to optimize horizontal well completions"

Source: Sutton, Rob "Horizontal Gas Well Geometry – A Look at Industry Practices/Outcomes", 4th Annual Appalachian Basin Gas Well Deliquification Workshop, Jun 2013

Tulsa University Horizontal Well Artificial Lift Project (TUHWALP)

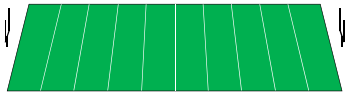
- Investigate Multiphase Flow Behavior in Horizontal Wells
- Investigate Artificial Lift Techniques in Horizontal Wells
- Develop Guidelines and Recommended Practices for Horizontal Wells

http://tuhwalp.ens.utulsa.edu

3. Deep, long, slender well geometries

- TVD ≈ 10,000 ft
- Lateral section ≈ 5,000 ft

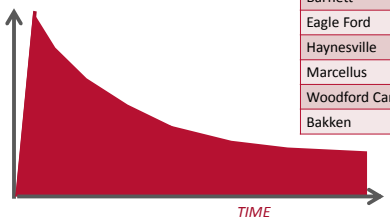
$$\frac{\text{4" ID bore}}{\text{5,000' lateral}} = \frac{\text{¼" straw}}{\text{104 yards}}$$



4. Rapidly changing production rates

Must plan for a wide range of production rates

Shale Play	1st Year Typ Decline Rate
Barnett	65%
Eagle Ford	75%
Haynesville	81%
Marcellus	64%
Woodford Cana	59%
Bakken	80%



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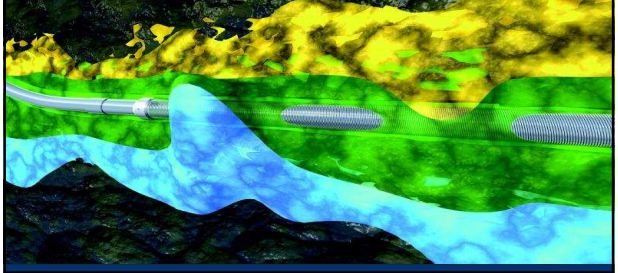
5. Uncertain inflow phase distribution

What is the production from each zone?



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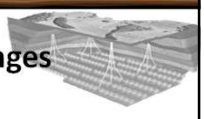
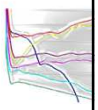
Production Challenges



1. Sluggy and turbulent flow
2. The impact of well geometry on EUR
3. Deep, long, slender well geometries
4. Rapidly changing production rates
5. Uncertain inflow phase distribution



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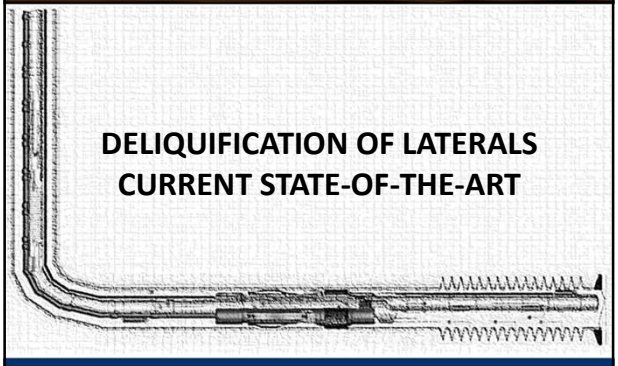
DELIQUIFICATION OF LATERALS CURRENT STATE-OF-THE-ART



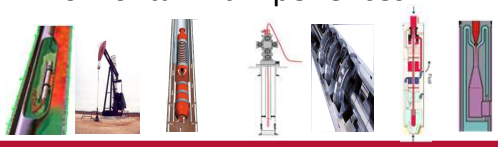
"Emerging" Horizontal Artificial Lift Technologies

- Surfactants to turn turbulent liquids to foam
- Gas Lift – Increase velocity
- Flow Geometry Alteration – Decrease Flow X-sectional Area
- Combination Applications
- Dual "Connected" Horizontal Well Application

The best form of lift for a loaded up gas well is:

- Reciprocating Rod Lift
- Plunger Lift
- Foam Lift
- Gas Lift
- All of the Above, Depending on wellbore and reservoir conditions
- None of the Above

Horizontal Lift Experiences



	Gas Lift	Rod Lift	Plunger Lift	Capillary	ESPs	Piston Pumps	Jet Pumps
Gas shales	Preferred	Lower BHP	Higher GLR	Foam lift, inhibition	-	Low volume liquid	Frac fluid flow-back, Initial unloading
Oil shales	Limited	Preferred	-	Inhibition	High perm, choked, high volume	< 200 bpd	

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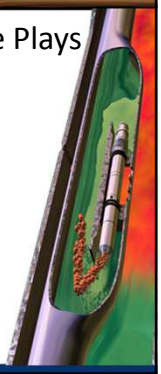
Continuous Gas Lift in Shale Plays

- Preferred for gassy shale plays for initial production
- Drawdown limitations
  - Unloading, SBHP ≥ 0.3 psi/ft
  - Continuous, FBHP ≥ 0.08 psi/ft
- Typically lifting from the heel
  - Gas lift extended into the lateral can provide velocity enhancement
- Typically replaced with rod lift, plunger lift, or capillary as production declines



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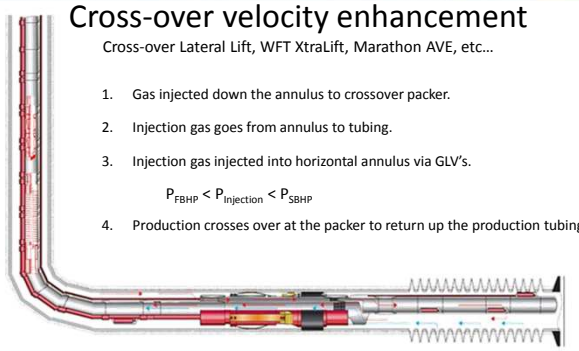
Cross-over velocity enhancement

Cross-over Lateral Lift, WFT XtraLift, Marathon AVE, etc…

1. Gas injected down the annulus to crossover packer.
2. Injection gas goes from annulus to tubing.
3. Injection gas injected into horizontal annulus via GLV's.

   $P_{FBHP} < P_{Injection} < P_{SBHP}$
4. Production crosses over at the packer to return up the production tubing.



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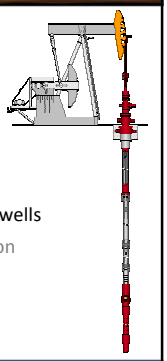
Rod Lift System

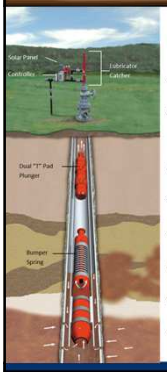


- Most common lift method in shale
- Broadest operating envelope
- Maximum drawdown

But…

- Large surface pumping units required for deep wells
  - May be oversized for low volume production
- Efficiency affected by gas
- Durability affected by particulate matter

Plunger Lift



- Lowest-cost lift method for low volume high GLR wells
- Requires no outside energy source; uses well's energy to lift
- Rig not required for installation
- Easy maintenance
- Removes paraffin deposits
- Handles gassy wells
- Good in deviated wells
- Can produce well to depletion

Plunger Lift 'Rules of Thumb'

Liquid Production

- 5 to 50 BBLS/day typical
- 200 BBLS/ day max

Gas Production Required

- 500 scf/ BBL / 1000ft (Packerless)
- 1000 scf/ BBL / 1000ft (Packer)

Depth Max

- 19000 ft

Deviation

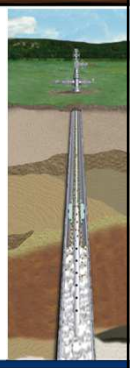
- 60° Inclination
- 4°/100ft DLS

Pressure Drive

- Use Load Factor

$(P_{CSG} - P_{TUB}) / (P_{CSG} - P_{LINE}) < 0.5$

Dewatering Breakthrough in the Barnett Shale



Challenge
- Dewater 4000 foot laterals
- Varying water inflow

Solution
- Broad concentration range surfactant
- Surfactant delivered to the toe

Results
- Stable foam along lateral
- Increased gas production.

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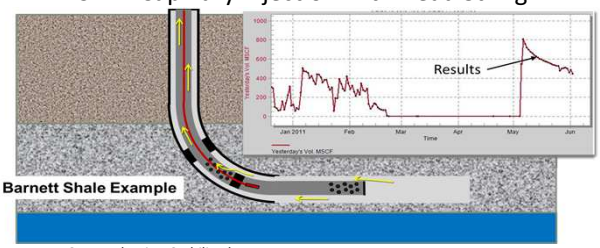
iCVR+ Capillary Injection with Dead String



- Gas Production Stabilized
- Water Unloading Rate Doubled
- Discontinued Gas Lift Compression

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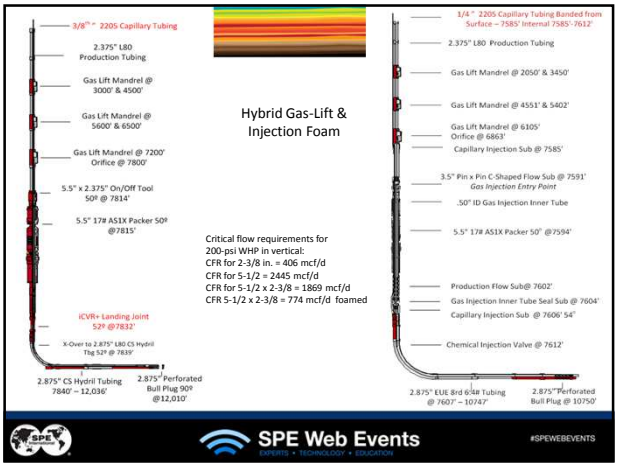

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Assuming wellbore geometry affects wellbore loading in a horizontal well, what is the best trajectory for the lateral from effective liquid unloading perspective?

- Toe Up
- Toe Down
- Flat
- Doesn't matter

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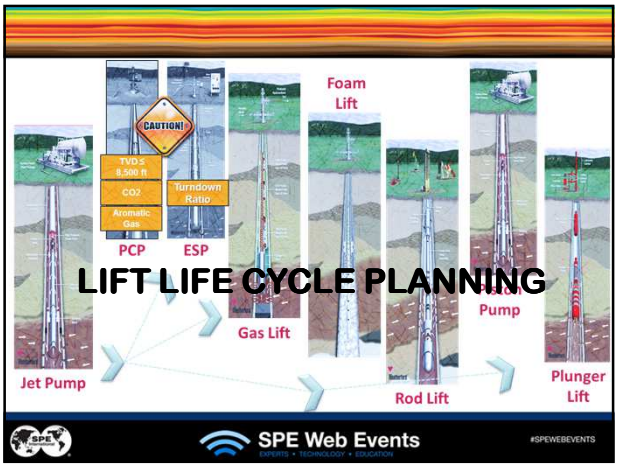
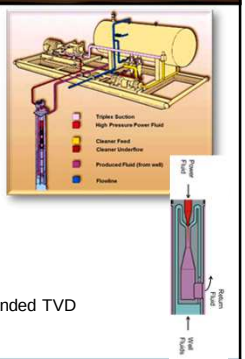


Hydraulic *Jet* Pumps



- High volume liquid removal:
  - Frac Flow-back
  - Initial well unloading
- Not affected by particulate matter
- Wireline or circulation run & retrieve
- High power usage
- Efficiency impacted by gas
- 1 foot of liquid head for every 10 feet of landed TVD

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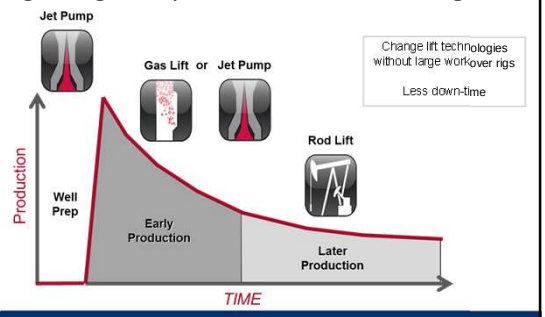
Jet Pumps for Frac Flow-back

Freestyle jet pump recovers frac fluid 5 times faster than swabbing, saving up to $200,000 per well.

- Location: North America
- Well type: Oil & Gas
- Hole Angle: Vertical/Deviated
- Casing/Tubing: 5-1/2", 17 lb/ft csg
  2-7/8" tubing
- Real Results:
- Freestyle pump + portable surface unit used on all 4 wells
- Frac fluids recovery time:
  - 1-3 days for fracs < 15,000 BPD
  - 1-3 weeks for larger volume fracs

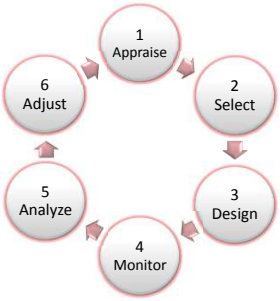
Integrating Completion & Lift Technologies



Importance of Monitoring & Surveillance

- Rapidly declining or fluctuating production rates require constant monitoring and lift adjustments.
  - Surface flow measurement at well site is more common.
  - Downhole pressure and temperature monitoring are available to help with lift surveillance, production optimization, and zonal allocation.
- Continuous measurement data streams need to be compacted into actionable information with tightly-coupled lift analysis algorithms built into data visualization platforms.

Production Optimization Process



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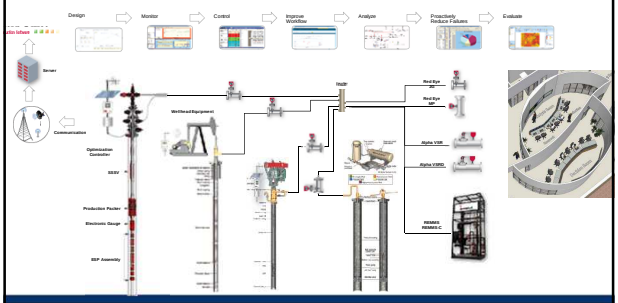
A Systems Approach to Optimization



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Well Construction Best Practices

- Consider well geometry during well placement and well design planning
  - Toe-up trajectory > 90.5° deviation
  - Minimize undulations
- *Plan for the "long term"*
  - Ensure the vertical section casing geometries will permit future installation of sufficiently sized ALS technology
  - Intentionally plan/control vertical transition to horizontal well
  - Control tortuosity of horizontal section of well

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Lessons learned for deliquifying laterals

- In gassy wells consider gas lift
- For wells in which rapid decline rates are expected, plan for transition to:
  - Rod pumps
  - Hydraulic piston pumps (deep low volume production)
  - Plunger lift (gassy wells)
  - Area reduction and foam (gassy wells)

Lessons learned for deliquifying laterals

- Mechanical pumps can pump from low spots but are not effective in “sweeping” liquids through laterals.
- Mechanical pumps can have gas interference issues.
  - Gas anchors are required for mechanical pumps in gassy wells.
- Where possible, land mechanical pumps:
  - In vertical section 50 to 100 ft above the liner top
  - In straight sections if within the deviated section
- Use continuous lift optimization (surveillance, analysis, adjustment)

Disclosure Statement

- The views expressed in this presentation are those of the presenter and are not necessarily the opinions of the Weatherford organization or any officer of the Weatherford organization.