Optimize and Troubleshoot Plunger Lift Wells

David Cosby, P.E.
Shale Tec LLC
Why optimize

Planning

Optimize production

Detect & troubleshoot

Sustain peak production
Why Optimize?

What is an optimized well?

Meets daily production goal?
No missed plunger cycles?

Produce at or above 80% of AOF?
20% production increase?

500 to 1000 fpm plunger cycle?
Rapid payback?

“An optimized plunger lift well is a well that is operating at the maximum number of cycles necessary to generate the lowest average flowing bottom hole pressure with the available reservoir energy.”

ALRDC Guidelines and Recommended Practices

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Why Optimize?

Why is it important?

Inflow Performance Relationship

- 60 psi

46% of AOF

$ 60,480 / year @ $ 4/mcf

79% of AOF

ABSOLUTE OPEN FLOW!

42 mcf/d

“Gas Well Deliquification” by Lea, Nickens, Wells
“Natural Gas Engineering Handbook” by Guo, Ghalambor

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Why Optimize?

Why is it important?

DAILY PRODUCTION

LOST PRODUCTION

NATURAL DECLINE CURVE

CASING PRESSURE

LIQUID LOADED DECLINE CURVE

LOST PRODUCTION

$187,200 / year @ $4/mcf

FLOW RATE (mcf)

PRESSURE (psi)

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Planning

“Getting the Right Things Done” by Pascal Dennis

“Creating a Lean Culture” by Dennis Mann

“The Toyota Way” by Jeffery K. Liker

Mental Models

Fire Fighting / Squeaky Wheel

“Problems are nuggets to be mined, not garbage to be buried”
Where are we now?

1. Define True North
2. Develop the plan
3. Deploy the plan
4. Monitor the plan
5. Solve the problems
6. Improve the system

Where do we need to go?

How do we get there?

Understand the mess!

1. Target? Actual? Gap?
2. What prevents us from meeting our target? (fishbone)
3. What are the causes in order of importance? (pareto)
4. What actions will address the most important causes? (A3)

What’s the Process?

How can you tell it’s working?

What are you doing to improve it?
Why are we missing production targets?

Planning

What are the causes? Fishbone!

Man
- Not enough people
- Absenteeism
- Training
- Motivation

Method
- Time per well
- No standard processes
- Insufficient data
- Non-Optimized Wells

Material
- Well Frac'd into
- Liquid loaded
- Drill rig on site
- Sanded in

Machine
- Line pressure issues
- Restrictions
- Limited technology
- Equipment failures

Equipment

Management
- Poorly defined goals
- Fire fighting culture
- Inadequate resources

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What are the causes in order of importance?

Wells producing below production target

- Liquid Loading: $500,000 / yr, 12 occurrences
- Not optimized: $350,000 / yr, 8 occurrences
- Surface Equipment: $120,000 / yr, 5 occurrences
- Personnel
- Pipeline
- Sanded-in
- Unknown
- Frac’d Into

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1. **WHY** are the wells liquid loaded?
   - Artificial lift was not installed prior to lost production

2. **WHY** was artificial lift not installed to prior to lost production?
   - We did not know the wells were about to liquid load

3. **WHY** didn’t we know the wells were liquid loading?
   - All of our resources are focused on operating existing plunger lifted wells

4. **WHY** are we spending so much time on existing plunger lift wells?
   - Our operators are untrained and we only have on-site control

5. **WHY** don’t we train our operators and invest in automation?
**Plan**

Understand the problem

"A problem well defined is a problem half solved"

1) Is the problem statement clear and accurate?
2) Has the systemic root cause been identified?

**DO**

Implement the plan

3) Has irreversible corrective actions been implemented for all root causes?

**CHECK**

Follow-up

4) Has a plan been identified to verify the effectiveness of all corrective actions?

**ACT**

Adjust

5) Has a plan been identified to standardize and save all lessons learned across all groups?

---

**CONTINUOUS PROCESS**

ENGRAIN IN COMPANY CULTURE!
Planning

What’s the plan? A3 – one 11” X 17” page!

FOCUS: Production

Performance, Gaps, Targets
✓ Show last years results
✓ Are we getting better or worse?
✓ Show 1, 3, 5 year targets
Tell the story with a chart!

Reflection on 2013 activities
✓ Assess 2013 activities.
✓ What worked, what did not?
✓ Please explain!

Rationale for 2014 activities
✓ How does last year affect this year?
✓ Any new factors to consider?
✓ What are our 3-4 areas of emphasis?
✓ How will these benefit us?

2013 Action Plan

<table>
<thead>
<tr>
<th>Goals</th>
<th>Activities</th>
<th>J</th>
<th>F</th>
<th>M</th>
<th>A</th>
<th>M</th>
<th>J</th>
<th>A</th>
<th>S</th>
<th>O</th>
<th>N</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identify Liquid Loaded Wells</td>
<td>Review decline curves</td>
<td></td>
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<td>Check critical flow rate</td>
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<td>Determine GLR</td>
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<td>Detemine AL type required</td>
<td>Low Gas to Liq Ratio</td>
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<td>High Gas to Liq Ratio</td>
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<td>Select vendors</td>
<td>Gas Lift Supplier</td>
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<td>Plunger Lift Supplier</td>
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<td>SCADA, Wireline, etc</td>
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<td>Select and train operators</td>
<td>Determine org structure</td>
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<td>Train operators</td>
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<tr>
<td>Begin installation</td>
<td>Install 1-5 systems</td>
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<td>Install 6-10 systems</td>
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</tbody>
</table>

Follow-up, Unresolved issues
✓ How will we check and report?
✓ Any unresolved issues, questions, support needed?
✓ What will we do about it?

SIGNATURES:

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Author:
Version and Date:
Optimize Production
1. Develop an artificial lift strategy
2. Install AL before production is lost
3. Standardized PL configuration
4. Set meaningful production targets
5. Remove restrictions
6. Prioritize wells daily
7. Optimize
8. Troubleshoot with DATA!
Optimize Production

Artificial Lift Strategy

Barnett Shale Example

A.L. GENERALLY NOT REQUIRED

GLR = 3

GLR = 5

GLR = 10

Actual Critical Flow Rate

MCF / D

BBLs / D

90 Mcf/d / 30 bbls/d = 3.0 GLR
150 Mcf/d / 30 bbls/d = 5.0 GLR
300 Mcf/d / 30 bbls/d = 10.0 GLR

For 7500 ft to BHS
400 scf / Bbl / 1000 ft = GLR of 3

Higher GLR wells are easier to operate, resulting in less non productive time

CONSIDER

- Multi-Stage PL
- Gas Assist PL
- Plunger Assisted Gas Lift

90 Mcf/d / 30 bbls/d = 3.0 GLR
150 Mcf/d / 30 bbls/d = 5.0 GLR
300 Mcf/d / 30 bbls/d = 10.0 GLR

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Optimize Production

Install BEFORE production is lost

Production Type Curve

Install AL Here!

Actual Critical Flow Rate

MCF / D

Months

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

3,000 2,500 2,000 1,500 1,000 500 0
Optimize Production

Standardize installation configuration

Controller location and attachment
Connection to EFM - trench or radio?
Communications with office
Lightening suppression

Emergency shut off
Sand cut probe

Dual master valve
Dual outlet lubricator
Platform to reach lubricator
Pressure transducer type, location
Pressure gauge type, locations
Solenoid supply – clean / dry gas!
Control valve type, trim, material
Ball valve model number
Hammer union locations
Optimize Production

Set meaningful production targets

Operating at:

☐ 40 % of Absolute Open Flow

or

☐ 80 % of Absolute Open Flow?

Target based on:

☐ Liquid loaded decline curve

or

☐ Long term natural decline curve
Prioritize wells daily

Production
- Address shut-in wells first
- Address wells producing below target

Leading indicators of future problems
- Missed arrivals
- Fast or slow arrivals
- Low battery voltage
- Increasing close times
- Pressures trending higher
- Ignored preventative maintenance
- Reliance on Trial and Error

Remove Restrictions
- Bottom hole spring
- Motor valve opening
- Scale, Paraffin
- 90 Deg elbows
- Chokes
- Orifice plates

Exceptions & Maintenance
 vs Milk runs

“Lifting costs reduced up to 75% with automation”

GWD Denver 2011
XTO / Ferguson Beauregard presentation
Optimize Production

Plunger Lift Calculator
- Daily cycles required
- Lift pressure required

Select Plunger
Fall time less than time to build pressure
Consider particulates

Cycle plunger & record
- Liquid load
- Lift pressure
- Plunger velocity
- Production made
- Open & Close time

Minimal sales time on initial cycles
Approximately 500 to 1000 fpm
Optimize production, not velocity

Adjust to achieve
1. Sufficient lift pressure to open when fall time expires.
2. Achieve & maintain #1, then increase sales time.
3. Use faster falling or better sealing plunger as needed.
4. Control velocity with liquid load & lift pressure.
Ensures least backpressure on formation, thus most inflow from reservoir into well bore

“Simple on/off controllers are not effective for optimization of a plunger system.” ALRDC
### Optimize Production

#### Rules-of-Thumb Calculator

<table>
<thead>
<tr>
<th>INPUT US</th>
<th>SI Inputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tbg ID, In</td>
<td>1.995 in</td>
</tr>
<tr>
<td>Pcsg, psi</td>
<td>219.60 psig</td>
</tr>
<tr>
<td>Pitg, psi</td>
<td>202.60 psig</td>
</tr>
<tr>
<td>Line Pressure, psi</td>
<td>123.90 psig</td>
</tr>
<tr>
<td>Liquid 5G</td>
<td>1.00 dimless</td>
</tr>
<tr>
<td>Plgr Fall Vel in Gas, ft/sec</td>
<td>253.00 ft/min</td>
</tr>
<tr>
<td>Plgr Fall Vel in Liq, ft/sec</td>
<td>40.00 ft/min</td>
</tr>
<tr>
<td>Depth to Spring, ft</td>
<td>7969.00 ft</td>
</tr>
<tr>
<td>Fraction of gas in Slug (-0.8)</td>
<td>0.80 Fraction</td>
</tr>
<tr>
<td>Fudge Factor: Adjust Shut-in Time (&gt;1)</td>
<td>1.10 F. Factor</td>
</tr>
</tbody>
</table>

#### Results

- **Oilfield Results**
  - Oilfield Results
  - **Liquid Volume in Tubing**: 0.152 bbls
  - **Height of Gassy Liq, ft**: 195.30 ft
  - **Fall time thru gas, min**: 30.72 min
  - **Fall time through gassy liquid, min**: 4.91 min
  - **Total fall time, min**: 35.63 min
  - **Total Fall Time x F Factor**: 39.19 min
  - **Min. Req. CP to Begin Unloading**: 185.85 psig
  - **Min Plunger Arrival Time (>1000 Ft/Min)**: 7.97 min
  - **Max Plunger Arrival Time (<500 Ft/Min)**: 15.94 min
  - **Desired Liquid Production, Rate**: 0.60 bpd
  - **Plunger Liquid Removal Effcy (per cycle)**: 0.50 dimless
  - **# Cycles/Day to Remove Desired Liquid**: 13.19 cy/day
  - **Max # Cycles/Day - Using Cycle Time**: 26.12 cy/day
  - **Max Possible Liquid Production, Rate**: 1.98 bpd
  - **Minutes per Cycle**: 109.21 min
  - **Maximum Unloading Time, Min**: 15.94 min
  - **Maximum Afterflow Time, Min**: 54.08 min
  - **Minimum Required Gas Rate**: 3.19 McfD

- **SI Results**
  - **Liquid Volume in Tubing**: 0.024 m³
  - **Height of Gassy Liq, ft**: 59.83 m
  - **Fall time thru gas, min**: 30.72 min
  - **Fall time through gassy liquid, min**: 4.91 min
  - **Total fall time, min**: 35.63 min
  - **Total Fall Time x F Factor**: 39.19 min
  - **Min. Req. CP to Begin Unloading**: 1281.25 kPa
  - **Min Plunger Arrival Time (>1000 Ft/Min)**: 7.97 min
  - **Max Plunger Arrival Time (<500 Ft/Min)**: 15.94 min
  - **Desired Liquid Production, Rate**: 0.60 bpd
  - **Plunger Liquid Removal Effcy (per cycle)**: 0.50 dimless
  - **# Cycles/Day to Remove Desired Liquid**: 13.19 cy/day
  - **Max # Cycles/Day - Using Cycle Time**: 26.12 cy/day
  - **Max Possible Liquid Production, Rate**: 0.315 m³/day
  - **Minutes per Cycle**: 109.21 min
  - **Maximum Unloading Time, Min**: 15.94 min
  - **Maximum Afterflow Time, Min**: 54.08 min
  - **Minimum Required Gas Rate**: 0.507 m³/day
**FOUR STAGES**
- Fall (Gas, Liquid)
- Pressure Build
- Plunger Rise
- Production

**Plunger Fall Time**
- Varies with gas/liquid in tubing, tubing pressure, well condition (paraffin, scale)
- Too short fall time – fast arrivals and liquid loading
- Too long fall time – lost production

**Pressure Build Stage**
- Operate at lowest casing pressure practical (least backpressure)
- Use Foss and Gaul equation to estimate required pressure

**Plunger Rise Time**
- “Fast enough to avoid stalling, slow enough to avoid damage”
- 500 to 1000 fpm is a guideline. Optimize production.

**Production Stage**
- Same amount of liquid in the tubing on every cycle
- Little to no sales time until pressure build stage time is zero
- Critical velocity or increase in CP to indicate liquid in tubing
- Allow lateral leg to unload for horizontal wells

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Consider opening on:
- Lift Pressure
- % of Foss and Gaul
- Load Factor

Consider closing on:
- Flow rate
- % of Critical flow rate
- Casing pressure rise

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Optimize Production

UNCONVENTIONAL PLUNGER EXAMPLE

Very short close time (Ex: 1 to 5 min)

Plunger falls against flow

Only round trip times recorded

Excessive plunger velocities possible
Troubleshoot
1. DETECT RAPIDLY
   - Real time alarms (Cry-out)
   - E-mail, text

2. DIAGNOSE WITH DATA
   - Then prescribe!

3. LOOK FOR VARIANCE

4. SOLVE ROOT CAUSE
   - Formal brainstorming, Pareto, Fishbone, 5 Why

5. BECOME A LEARNING ORGANIZATION
   - Reduce time between occurrence, detection and return to full production
# Troubleshoot

## Common Problems

<table>
<thead>
<tr>
<th>Plunger fails to surface</th>
<th>Slow arrivals</th>
<th>Fast arrivals</th>
</tr>
</thead>
<tbody>
<tr>
<td>✓ Stuck in lubricator</td>
<td>✓ Worn plunger</td>
<td>✓ Fall time too short</td>
</tr>
<tr>
<td>✓ Worn plunger</td>
<td>✓ Not enough pressure</td>
<td>✓ Plunger hung in WH</td>
</tr>
<tr>
<td>✓ Not enough pressure</td>
<td>✓ Too much liquid</td>
<td>✓ Tight spot in tubing</td>
</tr>
<tr>
<td>✓ Too much liquid</td>
<td>✓ Tubing restrictions</td>
<td>✓ Too much pressure</td>
</tr>
<tr>
<td>✓ Bad arrival sensor or cable</td>
<td>✓ Wrong plunger type</td>
<td>✓ Not enough liquid</td>
</tr>
<tr>
<td>✓ Plunger stuck in tubing</td>
<td>✓ Grease in tubing from WH valves</td>
<td></td>
</tr>
<tr>
<td>✓ Grease in tubing from WH valves</td>
<td>✓ Rapid fall plunger – shift rod stuck</td>
<td></td>
</tr>
</tbody>
</table>

### Control valve will not open

- ✓ No gas supply pressure
- ✓ Clogged gas supply filter
- ✓ Liquid in gas supply line
- ✓ Debris in solenoid valve
- ✓ Solenoid valve malfunction
- ✓ Hole in Motor Valve diaphragm

### Control valve will not close

- ✓ Liquid in gas supply line
- ✓ Debris in solenoid valve
- ✓ Solenoid valve malfunction
- ✓ Solenoid vent line plugged

### Motor valve leak

- ✓ Obstacle in Motor Valve trim
- ✓ Cut, worn trim (sand, particulates)
- ✓ Consider ceramic trim
## Troubleshoot

### Common Problems

#### Short battery life
- ✓ Inspect battery
- ✓ Inspect wires to solar panel
- ✓ Inspect solar panel
  - ✓ Clean
  - ✓ 45 Degree angle
  - ✓ Facing south
- ✓ Radio malfunction (amps)

#### Catcher will not trap plunger
- ✓ Inspect / replace spring and or ball
- ✓ Flow longer

#### Lubricator top seeps / leaks
- ✓ Lubricate threads
- ✓ Inspect “O” ring
- ✓ Grease “O” ring

#### Flow rate increasing at end of afterflow

#### Fishing neck mushroomed
- ✓ Lubricator spring worn, stuck or too stiff
- ✓ Excessively fast plunger runs

#### Motor valve closed, flow rate not zero
- ✓ Motor valve leak
- ✓ Calibrate flow meter

#### Fall time elapsed, CP not rising, OFF time remains
- ✓ Reduce shut-in time or open at a lower lift pressure

#### Fast, dry plunger runs. Liquid in tubing on each cycle
- ✓ Fall time too short

#### Missed run every 6 weeks or so – no other issues
- ✓ Meter tech on site - shut in meter run
Troubleshoot

Common Problems

- Casing Pressure
- Tubing Pressure
- Flow Rate
- Line Pressure

Control Valve Closed
- Tubing declines
- Flow rate observed

Control Valve Leak
Troubleshoot

Common Problems

Control Valve Closed

- Line pressure declines
- Possible Dump Valve Leak

Casing Pressure
Tubing Pressure
Flow Rate
Line Pressure
Troubleshoot

Common Problems

- Casing Pressure
- Tubing Pressure
- Flow Rate
- Line Pressure

Control Valve Open
- Well closed when flow rate is increasing
- Flow longer

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Troubleshoot

Common Problems

- Control Valve Closed
  - Casing and tubing equalize
  - Pushing liquid out of tubing
  Shorten close time or add a standing valve

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Sustain peak production
Training is not enough!

- Develop skill sets required for each critical position. Train and evaluate skill. PDCA!

Sustain peak production

<table>
<thead>
<tr>
<th>Skill</th>
<th>Operator A</th>
<th>Operator B</th>
<th>Operator C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well site safety</td>
<td>Complete</td>
<td>Required</td>
<td>Complete</td>
</tr>
<tr>
<td>Basics of liquid loading</td>
<td>Complete</td>
<td>Required</td>
<td>Complete</td>
</tr>
<tr>
<td>Basics of plunger lift</td>
<td>Required</td>
<td>Required</td>
<td>Complete</td>
</tr>
<tr>
<td>Well requirements for plunger lift</td>
<td>Required</td>
<td>Required</td>
<td>Complete</td>
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<tr>
<td>Surface and sub-surface equipment</td>
<td>Required</td>
<td>Required</td>
<td>Complete</td>
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<tr>
<td>Preventative maintenance</td>
<td>Required</td>
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<td>Complete</td>
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<tr>
<td>Controller and graphical user interface screen</td>
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<td>Complete</td>
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<tr>
<td>Optimizing plunger lift wells</td>
<td>Required</td>
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<tr>
<td>Troubleshooting plunger lift wells</td>
<td>Required</td>
<td>Required</td>
<td>Complete</td>
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<tr>
<td>Formal problem solving processes</td>
<td>Required</td>
<td>Required</td>
<td>Complete</td>
</tr>
<tr>
<td>EchoMeter - Track / locate plunger, tubing integrity, fluid levels</td>
<td>Required</td>
<td>Required</td>
<td>Complete</td>
</tr>
<tr>
<td>Formal team building skills</td>
<td>Required</td>
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<tr>
<td>E-mail, text, excel, etc.</td>
<td>Complete</td>
<td>Complete</td>
<td>Complete</td>
</tr>
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</table>

**Plunger Lift Certification**

- **Basic**
- **Intermediate**
- **Advanced**
Communicate clear responsibilities

- Central optimizer (Example)
  - Selects plunger lift algorithm and plunger
  - Selects set points
  - Monitors pressures, plunger cycles and production
  - Notifies field operator of current and potential issues

- Field operator (Example)
  - Well site safety
  - Coordinates all on site activities
  - Preventative maintenance and repairs
  - Occasionally monitors plunger arrivals

BOTH are critical to sustained peak production!

Who’s responsible for production?

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Implement a preventative maintenance program

- Inspection point, pass/fail criteria, technique, frequency for:
  - Plunger (Replace BEFORE production is lost)
  - Lubricator (Spring, catcher, “o” ring, connection to WH)
  - Bottom hole spring (Blockage?, Worn?)
  - Control and dump valves (No leaks!)
  - Arrival sensor, pressure transducers, wiring
  - Drip pot or gas scrubber (Check daily, drain)
  - Supply gas to solenoid valves (Clean, dry gas !)
  - Battery, solar panel, wiring
  - Orifice plate
  - Flow meter
  - Tubing integrity (EchoMeter or pressure test)
Summary
Plunger Lift Considerations

**Summary**

- Time frame after IP
- Critical rate for reservoir
- Decline Curve Analysis
- Erratic production
- Critical flow rate
- Intermittent, Swab, Foam

Clear liquid from tubing first (400 scf per bbl per 1000 ft lift)

Lift Pressure $\geq$ 2X Liquid load

- No Packer (or more gas)
- Same ID spring to spring
- Pressure check tubing

- Motor valve trim size
- Orifice plate
- Consistent line pressure
- Hold down assembly

Is liquid in the tubing?

Is gas volume sufficient?

Is gas pressure sufficient?

Good well integrity?

Significant sand, H$_2$S or CO$_2$?

Eliminate restrictions

Troubleshooting process known (NPT goal vs actual)?

Preventative maintenance program?

Trained operator?

Telemetry available?

Clean, dry supply gas?

Standard well head configuration defined?

TELEMETRY BENEFITS
- Lower lifting cost
- Less downtime
- Less equipment repairs
- Faster optimization
- Faster troubleshooting
- Improved site safety
- Leverage expert optimizer
- Daily prioritize wells
- Remote manual close
- Alarm on exceptions
- Leak detection

OPTIMIZE PRODUCTION

Max cycles

Smallest liquid loads

Lowest bottom hole pressure

Most Production

LIFT METHOD

<table>
<thead>
<tr>
<th>LIFTING COST COMPARISON ($ / Mcf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Lift</td>
</tr>
<tr>
<td>Plunger Lift – No Telemetry</td>
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<tr>
<td>Plunger Lift – With Telemetry</td>
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</tbody>
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February 24 - 26, 2014
2014 Gas Well Deliquification Workshop
Denver, Colorado
“Problems are nuggets to be mined, not garbage to be buried”

“Plunger Lifted Gas Wells”

“Good To Great: Why Some Companies Make the Leap .... And Others Don’t” by Jim Collins
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