Adapting Load Factor For Use In Unconventional Wells

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A TRUSTED TOOL WITH UNANTICIPATED RESULTS

- **Load Factor (LF)**
  - Plunger-Lift Control Parameter
  - Widely respected and widely used in industry
  - In use for decades
  - In Unconventionals, we often hear “It Doesn’t Work!”
  - When it “Doesn’t Work” people find they need to use a LF $<< 0.5$

- **Why?**
Complication 1: Pressure Relieving Standing Valve (PRSV)
- Can Make A Positive Impact to Production
- “Hold a load” Retain liquid in the tubing at equilibrium conditions
- Non-relieving valves used less and less due to uncertain load and inability to force liquid out of tubing
- Most commonly used in High Set or Horizontal Wells
- What do we even really understand about PRSV in Vertical Wells?
- When using LF control algorithm, user must modify approach!

Complication 2: Horizontal Wells
- Also, Inclination Complications
- Slug increases in head when it transitions from Horizontal to Vertical
- When using LF control algorithm, user must modify approach!
BREAKING DOWN THE PROBLEM

- **Step One:** Consider a Traditional Vertical Well
- **Step Two:** Consider a Traditional Vertical Well with a PRSV
  - This introduces a complicating factor.
  - We need to adjust for this factor.
- **Step Three:** Consider a Non-Vertical Well
  - Highly Inclined, Deviated, or Horizontal Well
  - This introduces another complicating factor…
  - We also need to adjust for this factor.
- **Step Four:** Consider a Non-Vertical Well with a PRSV
  - How can we still use Load Factor as a Control Parameter?
What is Load Factor?

- It is used as a control parameter to determine when to open the production valve in plunger lift wells.
- It is effectively a ratio of Hydrostatic Load to available power.

How is the parameter calculated?

\[ LF = \frac{(P_{Csg} - P_{Tbg})}{(P_{Csg} - P_{Line})} \]

- If LF > 0.5 Plunger likely won’t run
- If LF < 0.5 Plunger will likely run
STEP ONE: VERTICAL LOAD FACTOR

At Equilibrium, No Flow Condition
(Ignoring Gas Gradient)

Right before Kick-On

Force Balance @ EOT

\[ LF = \frac{(P_{Csg} - P_{Tbg})}{(P_{Csg} - P_{Line})} \]

\[ P_{Tbg} \]

\[ \rho gh_l \]

\[ P_{Csg} \]
SECOND, WHAT CHANGES WHEN WE INSTALL A PRSV?

- Goal of PRSV is to ensure we always retain liquid in the bottom of the tubing.

- Even when we are equalized we still have a load.

\[
(P_{Csg} - P_{Tbg}) = 0
\]
STEP TWO: VERTICAL PRSV LOAD FACTOR

- Force Balance Diagram with Added PRSV Spring

- At Kick-On, with a PRSV Installed

\[
\text{Load} = (P_{Csg} - P_{Tbg} + PRSV)
\]

\[
\text{Power} = (P_{Csg} - P_{Line})
\]

\[
LF = \frac{\text{Load}}{\text{Power}}
\]

\[
LF = \frac{(P_{Csg} - P_{Tbg} + PRSV)}{(P_{Csg} - P_{Line})}
\]

- We may have to reduce \((P_{Csg} - P_{Tbg} + PRSV)\) to maintain \(LF < 0.5\)

- May have to allow higher \(P_{Tbg}\) to keep \(LF < 0.5\)

Right before Kick-On

At Equilibrium, No Flow Condition (Ignoring Gas Gradient)
WHAT DOES THIS MEAN FOR THE PUMPER?

Installing a PRSV may require reducing \((P_{Csg} - P_{Tbg} + PRSV)\) to keep LF < 0.5

You could still use Load Factor as a control parameter if:

1.) You include the PRSV Spring-Force in your Automation LF Calculations

Or

2.) You hand calculate the LF Value (including PRSV Spring-Force) & directly input the parameter
THIRD, LET’S UNDERSTAND LOAD IN A HORIZONTAL OR INCLINED WELL

Simplification for Horizontals: Let’s Assume EOT is usually at or above Liquid Level in Casing
STEP THREE: HORIZONTAL OR INCLINED WELL

Hydrostatic Load increases as plunger “turns the corner” to Vertical

TVD_L = h_L + H
MD_L = Arc Length of h_L + H
STEP THREE: WHAT HAPPENS DURING THE LIFT CYCLE?

- Volume of fluid column above plunger remains constant
- Vertical height of fluid column above plunger increases
  - Liquid height changes from $\text{TVD}_L \rightarrow \text{MD}_L$
- During Plunger Rise, Hydrostatic Load Increases as liquid column becomes more vertical
- Initial available Power does not change
- May need to reduce initial load to ensure we can lift through Vertical
- How Much?
  - Probably need to reduce Load sufficiently to keep LF < 0.5
WHAT DOES THIS MEAN FOR THE PUMPER?

- High inclinations require reduction in \((P_{Csg} - P_{Tbg})\) to keep LF < 0.5

- You could still use Load Factor as a control parameter if you account for inclination in LF Calculations

\[
Load = (P_{Csg} - P_{Tbg}) \times \left(\frac{MD_L}{TVD_L}\right)
\]

\[
Power = (P_{Csg} - P_{Line})
\]

\[
LF = \frac{Load}{Power}
\]

\[
LF = \frac{(P_{Csg} - P_{Tbg}) \times \left(\frac{MD_L}{TVD_L}\right)}{(P_{Csg} - P_{Line})}
\]
STEP THREE: REAL LIFE EXAMPLE!

- BHA at 64° inclination,
- Initial Load $h_L = TVD_L = 50'$

- Once the plunger “turns the corner” past the KOP to vertical
- Volume conserved, height of liquid load increases to $h_L = 102'$

- New height was $MD_L$ at equilibrium

- Load increases by $102' / 50' = 2.04$ Times during plunger cycle

- Therefore, may need to reduce initial load to keep LF < 0.5
STEP THREE: REAL LIFE EXAMPLE!

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- Initial Load $h_L = \text{TVD}_L = 50'$

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STEP THREE: REAL LIFE EXAMPLE!

- BHA at 64° inclination,
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- Once the plunger “turns the corner” past the KOP to vertical
- Volume conserved, height of liquid load increases to $h_L = 102'$
- New height was $MD_L$ at equilibrium
- Load increases by $102' / 50' \times 2.04 \text{ Times}$ during plunger cycle
- Therefore, may need to reduce initial load to keep $LF < 0.5$
FINALLY, TYING IT ALL TOGETHER

Load increases both by PRSV & as plunger “turns the corner” to Vertical

Arc Length above KOP

Arc Length below KOP

TVD_L = h_L
MD_L = Arc Length of h_L

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STEP FOUR: ADAPTING LOAD FACTOR

- Modify Initial Force Balance Diagram with PRSV Spring Bias
- Need to account for increase of Load when “turning the corner”

- At Kick-On:
  \[ \text{Load} = (P_{Csg} - P_{Tbg} + PRSV) \]
  \[ \text{Power} = (P_{Csg} - P_{Line}) \]

- When “Turning the Corner”:
  \[ \text{Load} = (P_{Csg} - P_{Tbg} + PRSV) \times \left(\frac{MD_{L}}{TVD_{L}}\right) \]

- Therefore, need to further reduce to keep LF < 0.5
  \[ LF = \frac{\text{Load}}{\text{Power}} = \frac{(P_{Csg} - P_{Tbg} + PRSV) \times \left(\frac{MD_{L}}{TVD_{L}}\right)}{(P_{Csg} - P_{Line})} \]
Installing a PRSV may require reducing \((P_{Csg} - P_{Tbg} + PRSV)\) to keep LF < 0.5

High inclinations require further reduction in \((P_{Csg} - P_{Tbg}) \times \left(\frac{MD}{TVD_L}\right)\) to keep LF < 0.5

You could still use Load Factor as a control parameter if you combine & account for both PRSV & inclination in LF calculations

\[
Load = (P_{Csg} - P_{Tbg} + PRSV) \times \left(\frac{MD}{TVD_L}\right)
\]

\[
Power = (P_{Csg} - P_{Line})
\]

\[
LF = \frac{Load}{Power}
\]

\[
LF = \frac{(P_{Csg} - P_{Tbg} + PRSV) \times \left(\frac{MD}{TVD_L}\right)}{(P_{Csg} - P_{Line})}
\]
In Summary

- **Step One**: Consider a Traditional Vertical Well
  \[ LF = \frac{(P_{Csg} - P_{Tbg})}{(P_{Csg} - P_{Line})} \]

- **Step Two**: Consider a Traditional Vertical Well w/ a PRSV
  \[ LF = \frac{(P_{Csg} - P_{Tbg} + PRSV)}{(P_{Csg} - P_{Line})} \]

- **Step Three**: Consider a Non-Vertical Well
  \[ LF = \frac{(P_{Csg} - P_{Tbg}) \cdot \left( \frac{MD}{TVD} \right)}{(P_{Csg} - P_{Line})} \]

- **Step Four**: Consider a Non-Vertical Well w/ a PRSV
  \[ LF = \frac{(P_{Csg} - P_{Tbg} + PRSV) \cdot \left( \frac{MD}{TVD} \right)}{(P_{Csg} - P_{Line})} \]

  If LF > 0.5 Plunger likely won’t run
  If LF < 0.5 Plunger will likely run
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