Liquid and Gas Flow Monitoring in Plunger Lift

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Presentation Outline

• Dynamic pattern recognition (DPR) technology
• Sample gas flow results
• Challenge of liquid production calibration
• Interim approach to liquid production monitoring
• Initial liquid production results
• Conclusions / discussion
Dynamic Pattern Recognition (DPR)

- Our methods developed over 20+ years in government and commercial contracting
- Previously employed in a broad range of applications
- Uses system dynamics as a basis for operational monitoring
Instrument Approach
Dynamic Pressure Sensor

- Commercially available
- Sensitive to small scale dynamics of pressure
- Lower detection limit: 0.02 in H₂O (5 Pa)
- Intrinsically safe (Div 1, Zone 0)
- Rugged, stable, reliable
Automation Instrument Concept

Sensor mounted on the well piping sends raw data to a processor board.

Software provides the instrument capability.

Output sent to the well controller or SCADA system.
Dynamic pattern recognition:

• Computationally efficient and responsive.
• Can detect very small changes in flow.
• Provides capabilities that may not be available otherwise.

BUT:

Algorithm development depends on calibration, requires experience with full range of known operating conditions.
Sample Gas Flow Results

- Pink: our gas flow
- Yellow: actual gas flow
- Tubing pressure is an input

Gas flow results generally good, but depend on calibrating with data from many wells.
Challenge of Liquid Calibration

Liquid production:

- Difficult to measure, not real time.
- Calibration via separator tests or tank levels.
- These methods limit the accuracy of a resulting algorithm.

Path to a full-capability liquid instrument is long.
Example Separator Data

Cumulative Liquid Production (bbl) over time (min) with markers indicating well open, well shut, and plunger arrival.
Initial Liquid Capability: Arrival Timing

“Zeroth order flow instrument”
Improving liquid production monitoring requires

EITHER

• Much more calibration data and algorithm development (a long-term project)

OR

• Some way to determine rate of liquid delivery:
  – Plunger speed and
  – Void fraction of liquid slug
Simplified Plunger Model

- After blow-down, gas flow equals:
  - Gas displaced by plunger \((V_{pl} A_{tube})\)
  - plus
  - Gas leakage around plunger \((Q_{leak})\).

- Automation data can be used to identify plunger leakage and plunger velocity.

- Flow regime equation can estimate void fraction in liquid slug.
Plunger Leakage Equation

\[ Q_{\text{leak}} = C_d A_{\text{leak}} \sqrt{\frac{2\Delta p}{\rho_{\text{gas}}}} \]

Volumetric gas flow
Area of leak path (increases with wear)
Leakage discharge coefficient (nearly fixed for a given plunger)
Plunger pressure drop: weight of plunger over frontal area
Gas density (varies)

Leakage rate depends on gas density (only indirectly on liquid load)
Simplified Leakage Equation

For a given well, plunger, and level of wear,

\[ Q_{\text{leak}} = C_d A_{\text{leak}} \sqrt{\frac{2\Delta p}{\rho_{\text{gas}}}} \]

\[ = \frac{C_{\text{leak}}}{\sqrt{\rho_{\text{gas}}}} \]

General equation

For a given well, plunger, and level of wear.
Gassy Liquid Above Plunger

Void fraction (percentage gas content by volume) in gassy liquid column is a function of plunger leakage flow rate and pressure.

Gas leakage velocity in gap is high (typically of order 50 ft/sec).

Liquid film leaking down past plunger is very thin (typically < 0.001").

Leakage velocity does not decrease with plunger wear.
Void Fraction Estimate (70°F)
Estimating Leakage

Strategies:

1. Use an Echometer to time collar passings.
2. Use cumulative gas production, minus initial charge above liquid, to determine total leakage.
3. Use timing of plunger arrival to estimate mean plunger velocity and leakage.
4. Full model – uses instantaneous pressures and gas flow to converge on best available estimate.
State of Model Development

- With leakage established, plunger velocity and void fraction at liquid arrival are easy to estimate.
- Plunger fall estimate accurate, but is difficult to automate and will not work with bypass plungers.
- Full model estimation is also reasonable.
- Use of perseverance (carrying over knowledge from cycle to cycle) can greatly improve model accuracy / stability over time.
Sample Liquid Production Results

Circles: results for individual lift cycles
Diagonal line: Y = X
Point-by-point error: 0.126 bbl
Total actual: 2.83 bbl
Our total: 2.80 bbl
Future Work

• Obtain more data.
• Refine the model.
• Expand capabilities to provide real-time plunger velocity estimates:
  – Warn of rapidly approaching plunger.
  – Warn of plunger not likely to arrive.
  – Characterize wear state of plunger over time.
Conclusions

• Dynamic pattern recognition has the potential to provide a very useful well monitoring capability.

• Development of full-capability instruments is limited by ability to obtain calibration data.

• On-site modeling can help alleviate this.

• Modeling provides additional benefits:
  – Deriving useful information about production.
  – Improving identification of operational status.
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