Modeling and Control for Deliquification of Shale Gas Wells

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ABB
Overview

Deliquification in shale gas wells

- Optimal operation
- Plunger lift process
- Modeling of plunger lift
- Benefits of real time control
Optimal operation

... a stable operation

... higher than “normal production”

Mathematically

• Maximizes the production (or an objective)
• Minimize the operating cost
• Respect the system constraints i.e. stable operation
Regulatory control

- Base control
- Operates at a given set-point
- Given by
  - Operators
  - Optimization engineers
Minimum bottom-hole pressure

Bottom-hole pressure decreases => Production increase

Bottom-hole pressure decreases as the flow increases.

\[ Q_{\text{max}} \]

\[ P_{\text{static}} \]

\[ P_{\text{res}} \]
Advanced control

• Provides dynamic set-points to regulatory controller
• Maximize production / Minimize cost
• Responds quicker to disturbances
• But; needs detailed system information
A Model

- A representation of a particular system in mathematical equations
- For control/operation
  - First principles model
  - Black – box model
  - Grey- box model
- Allows us mimic the system, thus, predict and control

\[
\begin{align*}
\varepsilon \mu c \frac{\partial m}{\partial t} &= \frac{1}{r} \frac{\partial}{\partial r} \left[ k r \frac{\partial m}{\partial r} \right] \\
\frac{\partial m}{\partial r} \bigg|_{r_c} &= 0; \quad \frac{\partial m}{\partial r} \bigg|_{r_w} = q \frac{T P_{sc}}{T_{sc} \pi h k}
\end{align*}
\]
Artificial Lift system modeling

• Horizontal section
  – Reservoir properties
  – Fracing
  – Well completion

• Vertical section
  – Intermitted
  – Plunger lift
  – Gas lift
  – Pumps
Reservoir dynamics

- Inflow Performance Relationship (IPR) curve
- Proxy model
- Geological models
  - Single porosity model
  - Dual porosity model

Multiple simulators:
- Mwell (Meyer and Associates)
- Eclipse, Petrel (Schulmberger)
- WEM Shale (P.E. Moseley & Associates, Inc.)

Proxy model Knudsen et al. (2012)
Plunger Lift - Cycle

1. **Valve close**
2. **Liquid buildup**
3. **Plunger reaches well bottom**
4. **Valve open**
5. **Plunger lift**
6. **Liquid loads Pressure ↓**
Plunger dynamics

- Plunger moving up
- Gas out
- Plunger at Top
- Plunger moving down
- In gas
- In liquid
- Slug
- Plunger at Bottom

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Plunger falling

- Valve close
- Liquid build up
- Orifice flow across plunger
- Pressurization
  - In Tubing
  - In Casing

Pressure force:
\[(P_{\text{top}} - P_{\text{bot}})A_t\]

Drag force:
\[
\frac{c_D}{K_w^2} \left( \frac{1}{2} \rho v^2 \right)
\]

Avery & Evans (1988)
Plunger at bottom

- Valve close
- Liquid build up
- Gas pressurization
  - In Casing
  - In Tubing

![Graph showing flow vs. bottom-hole pressure](image_url)
Plunger rising

- Valve Open
- Gas flowing in tubing and casing
- Pressurization in tubing below plunger
- Force balance on plunger to calculate velocity and position

\[
\frac{f \rho_l v^2}{2} \frac{(L_s)}{d_t} \quad P_{top}A_t
\]

\[
P_{bot}A_t
\]

\[
(m_p + \rho_l L_s A_t)g
\]

\[
m_{p+s}
\]

Gasbarri & Wiggins (1997)
Plunger at top

- Valve Open
- Gas flowing in tubing and casing
- Gas flowing from tubing to sales line
Full model

S-1
Plunger Rising
Well Flowing

S-4
Plunger at bottom
Well Pressurize

S-2
Plunger at Top
Well Flowing

S-3
Plunger Falling
Well Pressurize

V. open

h = H

h = 0

V. close
Simulation - Pressure

![Pressure - PSI Graph](image)

- **Pressure (psi)** vs. **Time (min)**
  - Casing
  - Tubing
  - Line

**Graph Details:**
- Pressure ranges from 150 to 400 PSI.
- Time ranges from 0 to 200 minutes.
- The graph shows changes in pressure over time for different parts of the well system.
Simulation - Flow

Flow - MSCF/D

Time (min)
Simulation – Rise Velocity

Time (min)

Velocity - ft/m

Velocity

0 2 4 6 8 10 12 14 16 18 20

0 100 200 300 400 500 600 700

0 2 4 6 8 10 12 14 16 18 20
Real – Time control

Controller

Plunger lift model (mimic’s well)

Pressure, Flow and Arrival measurements
Insights

- Well simulation engine provides playground for operators
- Different control strategies can be compared for a given well
- The well dynamics demand a continuous change in control action. A constant timer/pressure based is sub-optimal.
- Advanced control rejects line pressure and well reservoir disturbances for optimal and stable operation
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