Monitor, Model & Maximize Intermittent Production

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Contents

• Distinguish different types of intermittent production
• Use pressure build-up for monitoring
• Review intermittent production modeling efforts
• Describe two-tank reservoir model
• Derive intermittent production capacity and reserves
• Maximize intermittent production
• Conclusions
Liquid Loading Cycle

$Q_{\text{min}}$ is minimum stable rate
a.k.a. critical rate
a.k.a. liquid loading rate

$Q_{\text{min}} \approx 200 \times 10^3 \text{ m}^3/\text{d}$
Intermittent Production (IP)

- Avoid production modes 2 and 3
- Results in storage of large near-wellbore volume of produced water
- Can take long time to remove
- Need to manage IP

Natural Cycle

Managed Cycle
Natural $\Rightarrow$ Managed Cycle

$Q_{\text{min}} \approx 12 \times 10^3 \text{ m}^3/\text{d}$

Metastable production is sub-optimum !!!
Intermittent Production Types

- Wait for liquid drop-out and (partial) drainage
  - Blow down tubing content, if $Q < Q_{min}$ then no liquid to surface and instead stored near-wellbore, very short cycles, avoid

- Wait for sufficient wellbore pressure recharging
  - Blow down completion content, with or without plunger, high enough pressure to achieve transient $Q > Q_{min}$ long enough to produce liquid to surface, pressure decreases as annulus volume increases, include standing valve to avoid drainage, short cycles
  - Natural & hydraulic fracs increase “annulus” volume

- Wait for sufficient reservoir pressure recharging
  - Depletion of near-wellbore reservoir, pressure high enough to achieve semi-steady state $Q > Q_{min}$, long cycles
Pressure Build-Up (PBU)

- Hydrostatic column after shut-in consists of gas column on top and liquid column on bottom.
- Liquid column depends on reservoir, well and production parameters, increases dramatically after liquid loading.
- Liquid column will drain into reservoir i.e. will decrease and ultimately disappear.
- Monitor liquid loading (and water production) via PBU.
• Column drainage can cause “hump” in case of differential depletion with higher pressure at top.
PBU – Reservoir Recharging

Longer time scale

Recharging Productive Zones

Temperature

Gas Rate

Pressure

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Pressure
Temperature
Gas Rate
Recharging
Productive Zones

Longer time scale

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0.259 E6Nm3/d
27.4 barg
56.0 DEG C
Modeling

- SPTgroup & TNO modeled liquid loading cycle for wellbore without annulus volume draining single tank
- Could not achieve $Q > Q_{\text{min}}$ i.e. could not unload liquid after 1st time liquid loading
- Significant near-wellbore reservoir pressure recharging is required to (temporarily) restore semi-steady state production i.e. WE NEED SLOW GAS
- Simplest semi-steady state approach to IP requires two-tank reservoir model where WELLBORE is connected to FAST tank which in turn is connected to SLOW tank
Two-Tank Model

- Minimum reservoir pressure in fast tank governed by liquid loading ($P_{\text{min,fast}}$)
- At onset of liquid loading reservoir pressure in slow tank is higher ($P_{\text{min,slow}}$)
- Slow tank gas volume at elevated pressure can be produced via intermittent production ($\text{OGIP}_{ip}$)

\[
\text{V}_{\text{slow}} = \text{OGIP} \cdot (1 - f)
\]
\[
\text{V}_{\text{fast}} = \text{OGIP} \cdot f
\]

Crossflow

\[
P_{\text{slow}}^2 - P_{\text{fast}}^2 = R \cdot Q
\]

Inflow

\[
P_{\text{fast}}^2 - \text{FBHP}^2 = A \cdot Q + F \cdot Q^2
\]

Outflow

\[
\text{FBHP}^2 = B \cdot \text{FTHP}^2 + C \cdot Q^2
\]

Liquid Loading Pressure

\[
P_{\text{min,fast}}^2 = B \cdot \text{FTHP}^2 + A \cdot Q_{\text{min}} + (C + F) \cdot Q_{\text{min}}^2
\]
\[
P_{\text{min,slow}}^2 = P_{\text{min,fast}}^2 + \left[\frac{R}{(1+f)}\right] \cdot Q_{\text{min}}
\]

Intermittent Gas Volume ($Z = 1$)

\[
\text{OGIP}_{ip} = \text{OGIP} \cdot (1 - f) \cdot (P_{\text{min,slow}} - P_{\text{min,fast}}) / P_i
\]
Two-Tank Model

1 month shut-down in middle of each year

\[ P_i = 350 \text{ bara} \]
\[ OGIP = 500e6 \text{ m}^3 \]
\[ f = 0.10 \]
\[ A = 20 \text{ bar}^2/(e3\text{m}^3/\text{d}) \]
\[ R = 100 \text{ bar}^2/(e3\text{m}^3/\text{d}) \]
Two-Tank Model

\[ P_i = 350 \text{ bara} \]
\[ OGIP = 500e6 \text{ m}^3 \]
\[ f = 0.10 \]
\[ A = 20 \text{ bar}^2/(e3\text{m}^3/d) \]
\[ R = 100 \text{ bar}^2/(e3\text{m}^3/d) \]
Two-Tank Flowing Material Balance

Use FMB to find $R$ and $f$

$$\text{OGIP}=2200e6 \text{ m}^3$$
$$f=0.03-0.06$$
$$R=43 \text{ bara}^2/(e3\text{ m}^3/\text{d})$$

**Flowing $P_{\text{res}}$**

**Closed-In $P_{\text{res}}$**

**Av. Gas Rate**
Two-Tank IP Capacity and Reserves

Initial IP Capacity
\[ Q_{ip} = (1-f) \cdot Q_{min} \]
or
\[ \text{Uptime} = (1-f) \]

IP Gas Recovery
\[ UR_{ip} = OGIP_{ip} \cdot \frac{(Q_{ip} - Q_{e})}{Q_{ip}} \]
where
\[ Q_{e} = \text{economic limit} \]

• Intermittent production more substantial for small fast tank fraction (f) and large contrast between cross-flow and inflow resistance (R/A)

• For small f and large R/A deliquification measures will show little initial benefit i.e. IP can fill the initial gap
  – Small productive tank is able to dispense slow gas to surface at such low reservoir pressure that it does not impede slow gas flow until slow gas pressure has dropped significantly
Optimize Intermittent Production

- Transient, short cycle IP: let wellbore pressure recharge sufficiently to blow liquid (plus plunger) to surface
- Semi-steady state, long cycle IP: do not let fast tank pressure recharge excessively to maximize slow gas cross-flow
  - Preferably \((P_{\text{res,fast}}-P_{\text{min,fast}}) < (P_{\text{res,slow}}-P_{\text{min,fast}})/10\) at all times
- Consider operational aspects of IP as well e.g. potential for sand production and well impairment due to clay swelling, sand fill or scaling
  - Some wells are not suitable for IP
Conclusions

- Do not entertain metastable production
- Use pressure build-up to monitor liquid loading and slow gas
- Distinguish transient short cycle intermittent production and semi-steady state long cycle IP
- Approximate semi-steady state IP by two-tank reservoir model
- After onset of liquid loading, loss of (average) capacity can be insignificant in case of small fast tank fraction
- Different strategies apply for optimizing transient IP and semi-steady state IP
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