Intermittent Production from Liquid Loaded Gas Wells

by

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Topics

1. The hydraulic model
2. Field test versus model prediction
3. Intermittent production
4. Downhole deliquification & injection
Typical production response in liquid loaded gas well

Intermittent production

- Recharge (reservoir)
- Drainage (well)
Liquid loading – problem definition

Water collects down hole and drains off

Water

Gas

P_{wf} \quad \text{DD} \quad P_{res}

Depth

OB
Well configuration with separate production and drainage intervals

Hydraulic model

- **upper zone**: gravity gas/water separation
- **lower zone**: water drainage under gravity
Hydraulic Model (cont.)

Producing (upper) & injection (lower) zones
- vertically separated to build up hydrostatic head
- lower injection zone pressure-depleted
- favourable permeability

Applications
- **Layered reservoir**: High pressure in upper zone and low pressure in lower zone can be used to perform downhole gas/water separation & injection driven purely by gravity
- **Thick reservoir**: liquid column builds sufficient head over pay zone for liquid drainage in lower part
Producing zone - liquid fall-out

Velocity profile:
liquid fall-out in lower part due to low upward velocity

In deviated well:
Turner critical velocity for liquid loading depends on tube inclination (Shell experiments)

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Back-up slide:

Turner criterion for liquid loading

There are many factors affecting the onset of liquid loading, e.g. large liner diameter and tubing inclination (Rijswijk experiments):

\[
v_t = 1.59 \frac{\sigma^{1/4} (\rho_L - \rho_g)^{1/4}}{\rho_g^{1/2}}
\]
Injection zone - Liquid build-up

Gas inflow rate:
hindered by liquid column providing back pressure

Water drainage:
Hydrostatic head and pressure depletion governs rate
Figure demonstrates that increased permeability thickness (product k*H) increases water drainage rate back into reservoir and decreases equilibrium liquid column height.
Back-up slide:

Gas rate hindered by liquid column providing back pressure in layered reservoir

\[
q_g = \frac{2\pi k (h_{f1} - h_{Liq block})(p_{Re s1} - p_{WH})}{\mu_g \left( \ln \frac{r_e}{r_w} + S \right)} + \frac{2\pi k (h_{Liq block})(p_{Re s1} - p_{WH} - \rho_w gh_{Liq block})}{\mu_g \left( \ln \frac{r_e}{r_w} + S \right)}
\]

- Injection rate modeled with Darcy:

\[
q_{inj} = \frac{2\pi k h\Delta p}{\mu \left( \ln \frac{r_e}{r_w} + S \right)}
\]

- Hydrostatic head

\[
\Delta P = \rho_L gh_{Liq} + P_{WH} - P_{Re sD}
\]
Test downhole separation/injection in Austrian field producing and injection zones connect by open sliding side door

Gas production ~50,000 m³/d

BHP ~55bar

- Gas production
- SSD open
- Compression on
- Compression out
- SSD closed

Downhole pressure in bar

Gas rate in m³/d

- lower gauge, 2076 m depth
- upper gauge, 1766 m depth

WHP

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Downhole gas/water separation & injection
Response simulated by hydraulic model @ test conditions

- BHP ~65 bar
- Injection rate ~100 m³/d
- Gas prod. ~50,000 m³/d

PBH [bar]
Time [h]
Production rate m³/d
Drainage rate, m³/d
Gas production, 1000x m³/d

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Intermittent production with downhole separation & gravity drainage controlled by automatic shut-in/start-up valve

Response simulated by hydraulic model
Back-up slide:

Definitions for next slide

**Normalised Gas rate**

Actual gas rate / Minimum gas rate at onset of liquid loading

**Normalised liquid rate**

Actual liquid rate / Liquid Drainage rate at equilibrium hydrostatic liquid column
Solutions for liquid unloading classified on basis of critical rates for gas production and liquid drainage

- **Cyclone Sep. + Gravity Inj.**
  - Normalized Gas Rate: $Q_{gas}/Q_{Turner}$
  - Normalized Liquid Rate: $Q_{prod}/Q_{inj}$

- **Gravity Sep. + Gravity Inj.**

- **Cyclone Sep. + Intermittent prod. or Injection pump**
  - Upper pressure
  - 1-1/2" gas lift tool with 1.125" ID pump
  - Anger separator and
  - Lower pressure
  - Lower Repair of Packer and Reducer with gravel packing
  - Cyclonic gas/liquid separation

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Liquid loading & unloading - discussion

Flow Characteristics
- dynamic multi-phase flows in long, thin deviated tubing
- dynamic interaction between far-field, near-wellbore reservoir & well
- backflow of condensate / water and back into reservoir

Dynamic Modelling
- time-scale of drainage process
- pressure-recharge and liquid drop-out around well
- transient state and PVT properties

Fit-for-purpose solution presented here
- Controlled intermittent operation to stabilise production
Concluding remarks

• A hydraulic model for depleting gas fields may predict capacity and characteristic time for intermittent production beyond onset of liquid loading.

• Predictions compare favourably to rates observed from test of downhole gas/water separation and injection (producing and injection intervals have significant vertical distance to build up hydrostatic head for liquid to drain into pressure-depleted lower zone).

• A liquid loaded well may be produced intermittently in controlled manner using automated shut-in valve; during shut-in time liquid is allowed to drain away.

• The application may be extended above critical gas rate by installation of cyclonic separation device, and above critical drainage rate by installation of downhole injection pump.

• Expected benefits from model are better predictability and control of gas capacity at tail-end production, and extended life of liquid loaded wells.