Gas Condensate PVT – What’s Really Important and Why?

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Goals

Give a review of the key PVT data dictating *recovery* and *well performance* of gas condensate reservoirs.

Understanding the importance of specific PVT data in the context of their importance to specific mechanisms of recovery and flow behavior.
Introduction

• Gas condensate engineering = Gas engineering + extra “magic”

• Which PVT properties are important … and why?

• Engineering tasks
Topics of Discussion

- PVT Experiments
- Initial Fluids in Place and Depletion Recoveries
- Condensate Blockage
- Gas Cycling Condensate Recoveries
- EOS Modeling

- Concluding Remarks
Three Examples

• **Example 1.** A small offshore “satellite” reservoir with high permeability ($kh=4,000 \text{ md-m}$), initially undersaturated by 400 bar, and with a test yield of 300 STB/MMscf.

• **Example 2.** A large offshore deep-water reservoir with moderate permeability ($kh=1000 \text{ md-m}$), initially saturated or near-saturated (?), large structural relief, and a test yield of 80 STB/MMscf. A single (and very expensive) discovery well has been drilled.

• **Example 3.** An onshore “old” undeveloped gas cap with well-defined initial volume (by production oil wells and pressure history), uncertain initial composition (estimated initial yield of 120 STB/MMscf), partially depleted due to long-term production of underlying oil, and low permeability ($kh=300 \text{ md-m}$).
PVT Priority Lists Vary for Each Reservoir

Different fields require different degrees of accuracy for different PVT properties -- depending on:

- field development strategy  
  \textit{(depletion vs. gas cycling)}
- low or high permeability
- saturated or highly undersaturated
- geography (\textit{offshore vs. onshore})
- number of wells available for delineation and development
PVT Experiments
Constant Composition (Mass) Expansion Test

Data

\( P_s \)

\( Z \)

\( V_{ro} - V_o/V_t \)
PVT Experiments
Constant Volume Depletion Test

Data
- $P_s$
- $y_i$
- $G_p/G$
- $Z$
- $V_{ro}$
Initial Fluids in Place (IFIP) and Depletion Recoveries

- Gas Z-factor
- Compositional (C_{6+}) Variation During Depletion
- Compositional Variation with Depth
- Dewpoint Pressure
- Gas-Oil Contacts
Gas Z-Factor

Z-factor is the only PVT property which always needs accurate determination in a gas condensate reservoir.

- Initial gas and condensate in place
- Gas and condensate recovery as a function of pressure during depletion drive
Compositional (C7+) Variation During (CVD) Depletion

- Forecast the condensate rate profile
- Calculate gas and condensate recovery profiles (neglecting water influx/expansion)
- Defining Gas Cycling Potential
Condensate Recoveries from CVD & CCE Data

\[ \text{RF}_{\text{OD}} = \left( 1 - \frac{(p/Z)_d}{(p/Z)_i} \right) + \frac{(p/Z)_d}{(p/Z)_i} \cdot \sum_{k=1}^{N} \frac{\Delta n_p}{n_d}_k \cdot \frac{1}{1/r_{si} + C_{og}} \]

\[ r_s \approx \frac{z_{6+}}{1 - z_{6+}} \cdot \frac{1}{C_{og}} \]

\[ C_{og} = \frac{RT_{sc}}{P_{sc}} \cdot \frac{P_{6+}}{M_{6+}} \]
# CVD Data Conversion to Surface Oil and Gas Recoveries

Based on Simplified Surface Flash (Surface Gas = C6- and Surface Oil = C7+)

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<th>C7+ Mole Weight</th>
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<td>C7+ Density</td>
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<td>Cog</td>
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Solution

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Surface Gas and Surface Oil Recovery Factors

CVD (Reservoir) Pressure, bara

Surface Gas
Surface Oil
Dewpoint Pressure

• Dewpoint marks the pressure where:

  – Reservoir gas phase
    (= producing wellstream)
    starts becoming leaner

  – Incipient condensate phase appears
Compositional Variation with Depth

- Effect of a gradient on IFIPs
- Prediction of gas-oil contact using a theoretical gradient model
- Effect of compositional gradients on depletion (and cycling) recoveries
Condensate Blockage
Near-Wellbore Steady State Region

*Relative Permeability*

\[ k_{rg} = f(k_{rg}/k_{ro}) \]

*“Pure” PVT*

\[ k_{rg}/k_{ro} = (1/V_{ro} - 1)(\mu_g/\mu_o) \]
Condensate Blockage
Near-Wellbore Steady State Region

\[ N_c = \frac{v_s \mu_g}{\sigma_{go}} \]
$V_{ro} = \frac{V_o}{V_t}$ of Flowing Mixture (=Produced Wellstream), %

(V$_{ro}$ not equal to Normalized Oil Saturation !)

Normal Range for Near-Wellbore Blockage Region

Lean GC

Rich GC

EOS $V_{ro}$ is 20% too low

EOS $V_{ro}$ is 20% too high
Gas Cycling

• Evaluating Gas Cycling Potential using Depletion (CVD & CCE) Data

• Evaluating Different Components of Condensate Recovery
  – Initial Depletion
  – Gas-Gas Miscible
  – Vaporization
  – Post-Cycling Depletion
Initial Pressure = Dewpoint
Gas Cycling Ultimate Condensate Recovery

Cycling Above Dewpoint

\[ RF_{\text{out}} = RF_{oD} + E_S \cdot RF_{oM} + (1 - E_S) \cdot RF_{oDx} \]

Cycling Below Dewpoint

\[ RF_{\text{out}} = RF_{oD} + E_S \cdot (RF_{oM} + E_V \cdot RF_{oV}) + (1 - E_S) \cdot RF_{oDx} \]

\( E_S = \) final sweep efficiency at the end of cycling

\( E_V = \) final efficiency of vaporized retrograde condensate
## Gas Cycling Ultimate Condensate Recovery

### Data from CVD and CCE

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<th>$B_{gd}$ (m$^3$/Sm$^3$)</th>
<th>$V_{isg}$ (cp)</th>
<th>npw/nd</th>
<th>Z-factor</th>
<th>$V_{ro}$ (%)</th>
<th>RF$_{GD}$ (%)</th>
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“Representative” Samples

• “Reservoir Representative”
  – Any uncontaminated fluid sample that produces from a reservoir is automatically representative of that reservoir. **After all, the sample is produced from the reservoir!**

• “Insitu Representative”
  – A sample representative of the original fluid in place (usually of a limited volume within the reservoir)

  – **Accuracy of PVT Data ≠ Insitu Representivity of Sample**
EOS Modeling

- Molar composition and $C_{7+}$ Properties
- Splitting the plus fraction (3-5 $C_{7+}$)
- Tuning EOS parameters
- “Common” EOS model for multiple reservoir fluids
- Reducing number of components (“pseudoizing”)
## Pseudoization Example

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**Note:** The image shows a complex diagram with labeled components and connections, indicating a pseudoization example. Each component is assigned to a specific EOS number, and the diagram illustrates the relationships and connections between these components.
EOS Modeling

Generating Black-Oil PVT Tables

• Extrapolating saturated tables
• Non-monotonic saturated oil properties
• Consistency between black-oil and EOS models
• Handling saturated gas/oil systems
• Initializing reservoirs with compositional gradients
Definition of Black-Oil PVT Properties

\[
B_o = \frac{V_o}{V_{oo}} = \text{oil formation volume factor}
\]

\[
R_s = \frac{V_{go}}{V_{oo}} = \text{solution gas-oil ratio}
\]

\[
B_{gd} = \frac{V_g}{V_{gg}} = \text{dry gas formation volume factor}
\]

\[
r_s = \frac{V_{og}}{V_{gg}} = \text{solution oil-gas ratio}
\]
The term \( r_s/B_{gd} \) is the quantity needed by "geologists" to convert reservoir gas pore volumes to surface oil – a kind of "oil FVF \((B_o)\)" for the reservoir gas phase.

For compositionally-grading reservoirs with a transition from gas to oil through an undersaturated (critical) state, the term \( r_s/B_{gd} = 1/B_o \) exactly at the gas-oil contact.
Conclusions

For calculation of initial gas and condensate in place the key PVT data are:

• Initial Z-factor
• Initial C_{6+} molar content

In terms of black-oil PVT properties, the two "equivalent" PVT quantities are:

• B_{gd}
• r_s/B_{gd}
Conclusions

The constant-composition and constant-volume-depletion tests provide the key data for quantifying recovery of produced gas and condensate during depletion.

Above the dewpoint depletion recoveries of gas and condensate are equal and are given by the variation of Z-factor with pressure.
Conclusions

For calculation of condensate recovery and varying yield (producing oil-gas ratio) during depletion it is critical to obtain

Accurate measurement of $C_{6+} (r_s)$ variation in the produced gas from a constant volume depletion test.
Conclusions

For near-saturated gas condensate reservoirs producing by pressure depletion:

- cumulative condensate produced is insensitive to whether the reservoir is initialized with or without a compositional gradient
- even though initial condensate in place can be significantly different for the two initializations
Conclusions

Oil viscosity should be measured and modeled accurately to properly model condensate blockage and the resulting reduction in gas deliverability.

The (CCE) oil relative volume $V_{ro}$ has only a "secondary" effect on the modeling of condensate blockage.
Conclusions

For gas cycling projects above the dewpoint, PVT properties have essentially no effect on condensate recovery because the displacement will always be miscible.

Only the definition of initial condensate in place is important. Gas viscosity has only a minor effect on gas cycling.
Conclusions

For gas cycling below the dewpoint, the key PVT properties are:

- Z-factor variation during depletion
- $C_{6+}$ content in the reservoir gas during depletion
- $C_{6+}$ vaporized from the reservoir condensate into the injection (displacement) gas.