The Importance of Fluid Characterization for Diagnosing Well and Reservoir Performance of Gas Condensate and Volatile Oil Wells

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About me

- 15 years experience with ConocoPhillips.
- I started as Production Engineer, and back and forth as a Reservoir Engineer afterwards.
- Various assignments:
  - Block B, Natuna Sea Indonesia
  - Subsurface Reservoir Technology, Houston
  - Various groups in Lower 48 onshore US
  - San Juan Basin, L48
  - Deep Water Exploration Gulf of Mexico
  - Central North Sea, UK – Currently as Reservoir Engineer for Judy and Jade fields
Course Objectives

- Share experience related to reservoir, well performance and PVT
- Pass on simple but useful concepts related to PVT, especially on GOR
- Serve as a reminder to not overlook production data
- Obtain feedback throughout the discussion
Outline

Field Overview

Basic Introduction to Reservoir Fluid Properties
• Gas Condensate
• Volatile Oil

Reservoir and Well Performance Related to Fluid Properties
• 1. GOR as a Reservoir Pressure Indicator
• 2. Depletion Mechanism Diagnostic Using GOR
• 4. GOR Observation Leading to Opportunity
• 5. GOR Reversal Reveal Multitank
• 6. Fluid Pressure Gradient
• 7. Calculating BHP from SIWHP
• 8. Echometer: A Cost Effective Fluid Level Detector
• 9. N2 Bullheading and Reservoir Pressure
• 10. Identify Liquid Loading Issue
• 11. High Critical Rate in Judy Wells
• 12. Knowing Where Your Remaining Gas
• 13. Oil API to complement GOR

Conclusion and Discussion
Judy Field

Location | Block 30/7a CNS UK
---|---
Formation | • Jurassic Fulmar Formation (Shallow marine)
 | • Triassic Joanne and Judy Formations (Fluvial) – main producing formation
HC type | Single phase near critical fluids
 | • Gas condensate
 | • Volatile oil
Initial Pressure | 8,750 psia
Temp | 280 – 300 °F
Sat. Pressure | 6,000 – 8,000 psia
Drive Mechanism | Primary Depletion with No/Limited Aquifer
Current Pressure (Producing Blocks) | 1,000 – 3,000 psia
Well count | 12 producers
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Conclusion and Discussion
Fluid Properties and CVD – Gas Condensate

- Constant Volume Depletion (CVD) experiment shows the liquid starts to drop out and the GOR increases below the dew point.
Depletion Study gives an overview of the pure depletion scenario assuming no recovery from liquid drop out within the reservoir.
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Conclusion and Discussion
1. GOR as a Reservoir Pressure Indicator

- Based on knowledge of the CVD, one can back calculate average reservoir pressure based on observed GOR (assuming pure depletion and immobile liquid dropout).
- This independent pressure calculation can be compared to measured pressure data.
- It is a very useful diagnosis on depletion status and the mechanisms.

The GOR can be used to obtain the reservoir pressure based on the CVD. Any disagreement with the measured pressure may suggest a different depletion mechanism.

The calculated pressure from the GOR, matched quite well with recorded pressure data, suggesting a pure depletion mechanism.
2. Depletion Mechanism Diagnostic Using GOR

- Both Ex.1 and Ex. 2 show wells producing under pure depletion behaviour.
- No water production supports these GOR observations

- Ex. 3: the GOR is low and even shows a reversal trend in 2010. Calculated pressure from the GOR is higher than the observed pressure. This indicates multilayer production with a large permeability contrast.
- Ex. 4: well show GOR reversal due to active aquifer support (GOR can’t be used to estimate reservoir pressure)
3. Using GOR for Production Allocation QC

- Constant Volume Depletion (CVD) simulates a pure depletion thus giving the maximum possible GOR.
- GOR from CVD can be compared with production data. **Observed GOR should not exceed the GOR from the CVD experiment.**

The example on the right shows a GOR increase above maximum limit suggested by the CVD experiment therefore suggest some issue in the production allocation.

- In this example, the incorrect GOR could be caused by:
  - Inaccuracy of the oil meter at very low oil rate.
- Solution:
  - QC your observed data.
  - Perform meter calibrations to fit the new flow rate range.

CVD simulates depletion process. The properties from CVD is very useful to be compared with observed production data.
4. GOR Observation Leading to Opportunity

- Well X is producing from the same formation as Well Y but has a lower GOR than Well Y.
  - Well X GOR=38mscf/stb vs. Well Y GOR=55mscf/stb

- This leads to the conclusion that Well X is not producing from the entire perforated interval.

- Subsequently a production logging tool (PLT) confirmed this analysis, and a re-perforation was performed.

- In addition to gas production increase the GOR suddenly increased closer to Well Y GOR.
5. GOR Reversal Reveal Multitank

- Under pure depletion GOR is expected to monotonically rise
- GOR reversal requires further explanation and can’t be ignored
- Possible GOR reversal explanation:
  - Multi layers/tanks performance
  - Aquifer support pushing the existing liquid saturation (movable oil saturation)
  - Composition gradient (unlikely – no data observed comp. gradient in Judy)

GOR reversal observed. In pure depletion, GOR expected to increase continuously.

Homogeneous Pure Depletion Theoretical GOR Trend
5. History Match with Multi-Tank Scenario

- Multi-tank concept is supported by rock quality contrast between Joanne (upper zone) and Judy (lower zone) formation.
- Adjacent well is a poor producer, characterized by poor Judy reservoir quality and high remaining pressure.
- A multi-tank model is able to reproduce the GOR reversal behaviour.

- [Graphs showing gas and oil rate control, as well as reservoir pressures for Joanne and Judy.]
6. Fluid Pressure Gradient

- PVT model (Equation of State) can be used to estimate the fluid properties during the production life of the well.

- Experience in Judy has shown a good agreement between observed data from surveys vs. calculated value.

- Knowledge of this fluid gradient is useful for calculating pressure along tubing and perforation.
7. Calculating BHP from SIWHP

- It is a cost efficient way to obtain pressure data during long term shut-in
- Challenge: uncertainty of fluid column and its pressure gradient
- Required Data:
  - Shut-in Well Head Pressure (SIWHP)
  - Fluid Gradient (Gas, Oil or Water) estimated from fluid properties or measurements
  - Liquid level depth
- How to improve the accuracy
  - One may inject a known gas (i.e. N2) to push the liquid level down until it reaches the perforation.
  - With a known gas column, the calculation become a simple single phase gradient. This is more accurate because we know the property of the injected fluid.

\[
P = \text{Grad}_{\text{gas}} h_{\text{gas}} + \text{Grad}_{\text{liquid}} h_{\text{liquid}}
\]
8. Echometer: A Cost Effective Fluid Level Detector

- Liquid level inside tubing can be detected using an Echometer survey.

- Echometer uses sound wave reflection to detect the liquid level.

- The accuracy is dependent on the sound velocity in the gas column. PVT model can be used to calculate sonic velocity.

- An Echometer survey is not only beneficial for getting pressure data but also helping to diagnose the condition of the well:
  - Investigate liquid loading issue
  - Detect restriction inside tubing (scale, salt, etc.)
  - Detect enlargement inside tubing (for example hole in tubing)
9. N2 Bullheading and Reservoir Pressure

- N2 Bullheading had been used in the Judy Field to help restart depleted wells
- Bullheading data has many further uses when properly planned and analysed
- The pressure response during bullheading can be used to understand the reservoir pressure and liquid level.
  - The pressure difference can be used to estimate the liquid level
  - Stabilized pressures can be used to calculate the reservoir pressure (BHP)
- Required data:
  - N2 pumping history (volume and pressure)
  - Wellhead pressure
  - N2 properties
  - Estimate of fluid gradient inside tubing

\[ \Delta P \approx \text{Liquid Level} \]

\[ \text{Reservoir Pressure} = \text{WHP} + \text{N2 Hydrostatic} \]

\[ \text{BHP}=1750+462=2200\text{psi} \]
\[ \Delta P=769\text{psi} \]
\[ \text{Est. Liq. Grad.}=0.295 \text{psi/ft} \]
\[ \text{Liquid Level}=\frac{\Delta P}{\text{Grad}} = \frac{769}{0.295} = 2606\text{ft} \]
10. Identify Liquid Loading Issue

- This is an example where the well suffers from liquid loading issues.
- The Echometer provides an insight in the liquid level in the tubing.
- In this case reservoir pressure calculated from the liquid level is still quite high, indicating the remaining HC potential.
- A low GOR also suggests the reservoir pressure is still relatively high.
- Poor reservoir properties (low productivity) can’t provide a gas rate above the critical lifting rate. Without any help, the well will continue to load up.

- Insert coiled tubing gas lift is planned to be installed in 2016 to overcome this issue.
10. Another Liquid Loading Example

- Adjacent well to the previous example
- Well producing from two reservoirs with large permeability contrast (high perm reservoir is depleted)
- The well can’t be restarted after shut-in (liquid loaded)
- Cross flow from high pressure (low perm) zones to depleted zones during shut-in builds up liquid around perforations.

Low Perm High Press

Depleted High Perm

Liq. Dropout from Cross Flow Gas

Echometer confirmed a liquid level at 4500ft above the perforations (~1300psi back pressure)
11. High Critical Rate in Judy Wells

- The critical gas rate is higher than the Turner equation suggests.
- Consequently many wells are liquid loaded (on cycle).
- A study was performed with key input wellbore data and PVT model.
- Possible explanation for high critical gas rate:
  - Big diameter enlargement in tubing section
  - High well deviation
- Solution:
  - Insert coiled tubing gas lift
  - Design more consistent completion diameter

![Diagram showing gas rate variations and well test data]

![Graph showing gas rate trends]

**Notes:**
- 8.5 MMscfd as liquid loading point
- Transient flow regime
- Pseudo-steady state

**Dates:**
- Jan 2013
- Feb 2013
- Mar 2013
- Apr 2013
- May 2013
- Jun 2013
- Jul 2013

**Allocation Gas:**
- Well Test Gas
12. Knowing Where Your Remaining Gas Is

- Productivity issues can give false impression of depletion
- GOR from the examples below suggest reservoir is not depleted, despite the declining gas production
- Resolving productivity issue through better well and completion design can unlock this potential, therefore don’t give up on poor wells.
13. Oil API to complement GOR

- It has been shown that GOR is a useful diagnostic tool.
- As reservoir pressure drops below the dew point, the liquid drops out in reservoir and surface condensate API gravity begins to increase.
- Therefore API can be used to complement GOR as a reservoir depletion signature.
- However, the API is not usually available unless sampling is performed as part of reservoir surveillance. It is recommended to collect the data during regular well tests.

American Petroleum Institute (API) gravity is an inverse scale standard of oil relative density as defined below:

\[
\text{API gravity} = \frac{141.5}{SG} - 131.5
\]

where SG is oil specific gravity relative to water.
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Conclusion and Discussion
Key Messages

- Understanding the fluid behaviour is a very important tool to help understand well performance and troubleshoot well problems.
- GOR is expected to change during the production of gas condensate and volatile oil, therefore gives insight into depletion mechanism in the reservoir.
- Don’t overlook your data and get the most of your available data:
  - Analyse and understand your observed data.
  - Compare expected and observed data.
  - Investigate any disagreements, as this will lead to a better understanding of the reservoir behaviour.
  - Design a data acquisition strategy to validate the analysis.