SPE DISTINGUISHED LECTURER SERIES

is funded principally
trough a grant of the

SPE FOUNDATION

The Society gratefully acknowledges
those companies that support the program
by allowing their professionals
to participate as Lecturers.

And special thanks to The American Institute of Mining, Metallurgical,
and Petroleum Engineers (AIME) for their contribution to the program.
Gas Condensate Reservoirs: Sampling, Characterization and Optimization

SPE Distinguished Lecture Series
2003 - 2004
Brent Thomas
Sample set for this Presentation:
What’s happening down under?

- Three fields of 5 Tcf +
- Insufficient liquids in country
- Maximize liquids recovery
- Gas ~ 1.75 - 2.00 USD/Mscf
Rest of world?

- A few gas condensate reservoirs we have worked on in South America
- Again multiple Tcf in place
- gas price - 1 – 1.50 USD/Mscf
- Africa
-  ~ 4 USD/Mscf (North) ~ 3USD (SS)
- Middle East
-  ~ 3 USD/Mscf
- North America
-  ~ 5 – 7 USD/Mscf baseline
Good and Bad

- 35% of GIP produced before dew point pressure
- 85% of total GIP recovered

- Only 10% GIP ultimately recovered
- Abandon the reservoir at the dew point.

What makes one retrograde reservoir so good and another so bad?
Presentation Outline

1. Pitfalls to Avoid in Sampling Condensate wells
2. Characterization of Gas Condensate Fluids
3. Production Considerations
4. Performance Optimization
Standard Technique:

1. Allow the well to clean up.
2. Flow at a low rate (lowest drawdown where stability is maintained). Capture liquid and gas samples.
3. Flow at a higher rate – capture liquid and gas samples.
4. Beneficial to obtain samples for at least three rates.

Stable flow rate and GOR are necessary conditions for sampling.
As a general expectation -

![Apparent GOR vs Flowrate](image)

- **Formation issues**: Points on the left side of the graph, indicating low apparent GOR at high flowrates.
- **Wellbore issues**: Points on the right side of the graph, indicating high apparent GOR at low flowrates.

The graph shows a scatter plot with flowrate on the x-axis and apparent GOR on the y-axis.
GOR vs Gas Rate - $28 \times 10^3 \text{m}^3/\text{d}$

0.989 MMscf/D
GOR vs Gas Rate - 120 $10^3$ m$^3$/d

4.24 MMscfD
As a general expectation -

![Apparent GOR vs Flowrate](image)

- Formation issues
- Wellbore issues
- Flowrate (MMscf/D)
- Apparent GOR (m3/m3)
Pressure Profile

Liquid Dropout vs Pressure

Pressure (Psia)

Radius (ft)

Liquid Fraction

Pressure (Psia)

0.73 MMscfD

1.5 MMscfD

1.50

0.73
In addition to liquid volume, look at heavier ends -

The heavier ends are already gone!
Impact on composition is significant.

- Liquids condense from the gas
- Liquids accumulate in the formation.
- Surface liquid is apparently lighter (less heavy ends).

The result - lower apparent dew point pressure and lower apparent liquid yield.
Potential Performance Impact

Average Flowrate (MMScf/D) vs. Years on Production

- Incorrect Dew Point
- Actual Dew Point

Legend:
- Diamond: Incorrect Dew Point
- Triangle: Actual Dew Point
For example:

Comparison of C15+ Mole Fraction Distribution
Gas Condensate Samples

MW 216

MW 206
Therefore:

Multi-Rate Sampling:
resolves Liquid – Vapor Ambiguities

Bottom-Hole Sampling:
resolves Liquid – Solid Concerns
For gas condensate reservoirs we recommend:

1. Perform multi-rate sampling

2. If any appearance of solids obtain BHS for reference on C12+.

3. Sample early in the life of the well/reservoir.
Presentation Outline

1. Pitfalls to Avoid in Sampling Condensate wells

2. Characterization of Gas Condensate Fluids

3. Production Considerations

4. Performance Optimization
1-D thinking

Reservoir Fluid
100 C & 3000 Psi

100 C & 2000 Psi

50 C & 500 Psi

20 C & 200 Psi
Reservoir Fluid
100 C & 3000 Psi

100 C & 2000 Psi

50 C & 500 Psi

20 C & 200 Psi

1 + 1 = 4 ??
We do it all the time in characterizing condensates.
For example -

- Gas rate
- Water-Gas Ratio
- Cond-Gas Ratio
- WH Pres

Yield

Gas Rate

bbl/MMscf)

70
60
40

MMscfD

1
2
3

sep-2001
06-Sep-2001
07-Sep-2001
08-Sep-2001
09-Sep-2001
16-Sep

70
60
40
Conclusion of the evaluation engineers -

- liquid yield was only 22.7 bbl/ MMscf
- fluid in situ is a wet gas
- no concerns are foreseen.

**Problem:** Rates were too high.

Change the rate and you change the yield.
Constant Volume Depletion - % Liquid Accumulation

\[ y = -9.8895 \times 10^{-9} P^2 + 1.6338 \times 10^{-4} P + 2.2456 \times 10^0 \]

\[ R^2 = 0.99916 \]

Graph showing the relationship between pressure (kPa) and liquid (% accumulation). The equation and the graph illustrate the empirical relationship derived from experimental data.
Presentation Outline

1. Pitfalls to Avoid in Sampling Condensate wells
2. Characterization of Gas Condensate Fluids

3. Production Considerations

4. Performance Optimization
My consideration? Increase Revenue!

It should be producing at three times the rate! Put it on compression! Get a bigger pump!
1. Interfacial Tension Effects

\[ \Delta P \propto \text{IFT/D} \]

- IFT increases as Pressure decreases
- At lower pressures, greater \( \Delta P \) will be required to produce similar flow rates.
IFT may increase very rapidly with decreasing Pressure.

\[ \frac{D}{\sigma} \alpha \]

Pressure

IFT

PCAP

0.0125

0.50

4520 psi

6000 psi

Increase of 40X
Bigger pump may be counter-effective!

Regain Permeability vs DP

20684 kPa
(3000 Psia)

Regain Gas Perm vs DP

13789 kPa
2000 Psia
Differential Pressure Profile - Vertical Well

Maximum gradient ~82 psi/ft

Radius (ft)

Bhfp - 400/0.28 mD
Bhfp - 40/0.28 mD
Bhfp - 40/0.10 mD
Lab gradient
After C3
2. Porous Feature Size Effects

![Permeability Reduction with Rock Quality Graph](image_url)
Beware!
Example:

Core 1 had a permeability of 256 mD, $\phi=17.4\%$.

Core 2 had a permeability of 39 mD, $\phi=18.5\%$.

Core 1 had 10X reduction in $K_G$ due to liquid

Core 2 had a 25% reduction in $K_G$ due to liquid
Integrated Cuttings Analysis

\[ \ln(K) = 9.33 + 5.75 \ln(\text{por}) + 0.737 \ln(\text{IS}) \]

Integral = 32.5

Optical Porosity & Perm = 10.9% & 0.41 mD
Figure 2: Generalized Pore-Size Distribution  
Routine Air Permeability = 120 mD

\[ y = 2.1565 \times 10^{-8}x^3 - 1.6312 \times 10^{-5}x^2 + 3.0942 \times 10^{-3}x + 1.0708 \times 10^{-2} \]

\[ R^2 = 0.9932 \]

Figure 3: Generalized Pore Size Distribution  
Routine Air Permeability = 1 mD

\[ y = 3.2961 \times 10^{-5}x^3 - 2.2918 \times 10^{-3}x^2 + 3.9049 \times 10^{-2}x + 2.1975 \times 10^{-2} \]

\[ R^2 = 0.9768 \]
If we only knew exactly how flow changes:

\[ dQ = \frac{\Delta P}{\mu L} \int_{0}^{R_{\text{Max}}} K(r) f(r) 2\pi r dr \]

Assume \( K(r) = r^2 \)
Permeability Contribution and Impairment

Fraction

Permeability
Impairment

Diameter of Pores (microns)

0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0

1 10 25 50 75 100 150 200 300 400

Permeability Contribution and Impairment

Fraction

Permeability
Impairment

Diameter of Pores (microns)

0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0

0.19 1.9 4.75 9.5 14.25 19 23.75 28.5 33.25 38
Figure 5: Model Impairment

Normalized Permeability

Permeability (mD)

> Dew Point  < Dew Point
Presentation Outline

1. Pitfalls to Avoid in Sampling Condensate wells
2. Characterization of Gas Condensate Fluids
3. Production Considerations

4. Performance Optimization
Cal Canal field, California:

“There were three simultaneous effects: a) the gas transmissibility drastically declined as a result of retrograde fallout around the wellbore b) the skin changed from negative to positive as a result of liquid blockage . . . and c) the production rate increased sharply, but rapidly declined to a much lower rate.”

SPE 13650, 1985, Roy Engineer.
Mass of hydrocarbon left behind?
What are the options:

- Blow it down.
- Implement pressure maintenance via different forms of gas cycling.

What is legal and what is moral?

In north America – only if it affects gas production.
Easiest Pressure maintenance-start above dew point pressure

Phase Loop Shrinkage with Cycling

Temperature (K)

Pressure (kPa)

Original

After cycling

Tres
More common approach:

Shrinkage w/ Cycling at Pres and Tres
Another factor is productivity

**Relative Permeability vs Gas Saturation**

- **Y-axis:** Relative Permeability
  - Values range from 0 to 1
- **X-axis:** Gas Saturation
  - Values range from 0.000 to 0.800

Legend:
- **Red diamond:** Gas
- **Black square:** Condensate
Ultimately for cycling optimization:

1. How much of the liquid will be lost w/o cycling.
2. What will be the effect on gas rates?
3. What can you recover with cycling?
4. What are your objectives - short term/long term?
Optimization for recovery of liquid drop out

Total Revenues - Costs

Assuming that liquid dropout does not significantly affect gas rate:
In summary of optimization:

- how much hydrocarbon will be left behind
- how much can be re-vaporized/ kept from condensing
- gas price – 6 Mscf/BOE
- When gas price is high, liquid recovery will be insufficient incentive to implement gas cycling
- if gas rates are severely impaired then cycling/ stimulation is only option
Presentation Outline

1. Pitfalls to Avoid in Sampling Condensate wells
2. Characterization of Gas Condensate Fluids
3. Production Considerations
4. Performance Optimization
Benefits of SPE Membership

- Monthly *Journal of Petroleum Technology (JPT)*
- Access to 25+ free Technical Interest Groups (TIGs)
- Member discounts on technical papers, journals and conference registrations
- Networking opportunities within the SPE community
Benefits of SPE Membership

- Opportunities to participate in local Section activities
- Access to industry resources
- Leadership development and volunteer opportunities
- Career-building opportunities