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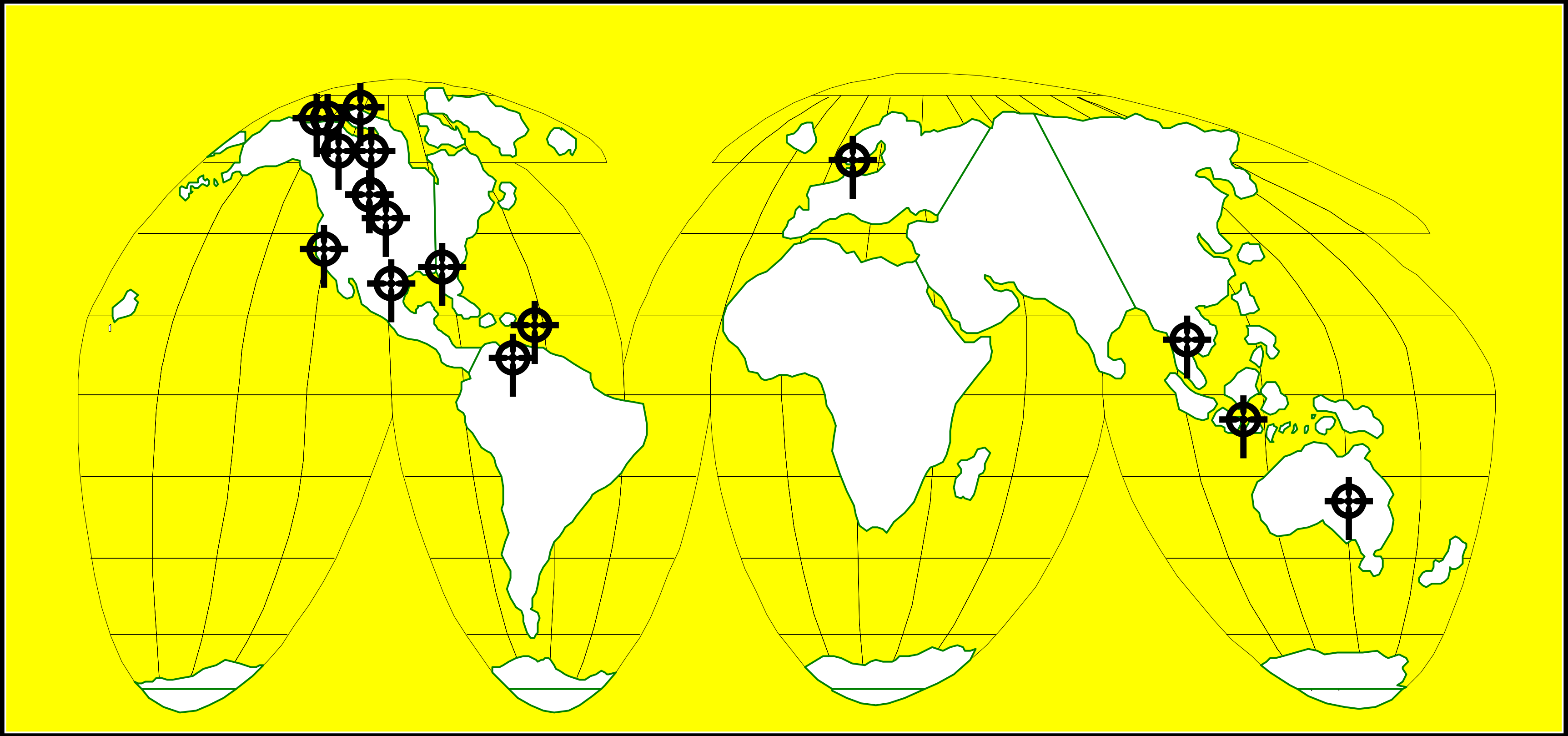
Gas Condensate Reservoirs: Sampling, Characterization and Optimization

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

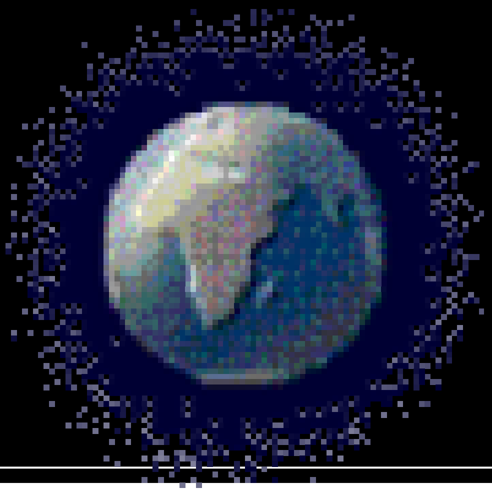
- ~ 4 USD/Mscf (North) ~ 3USD (SS)

-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

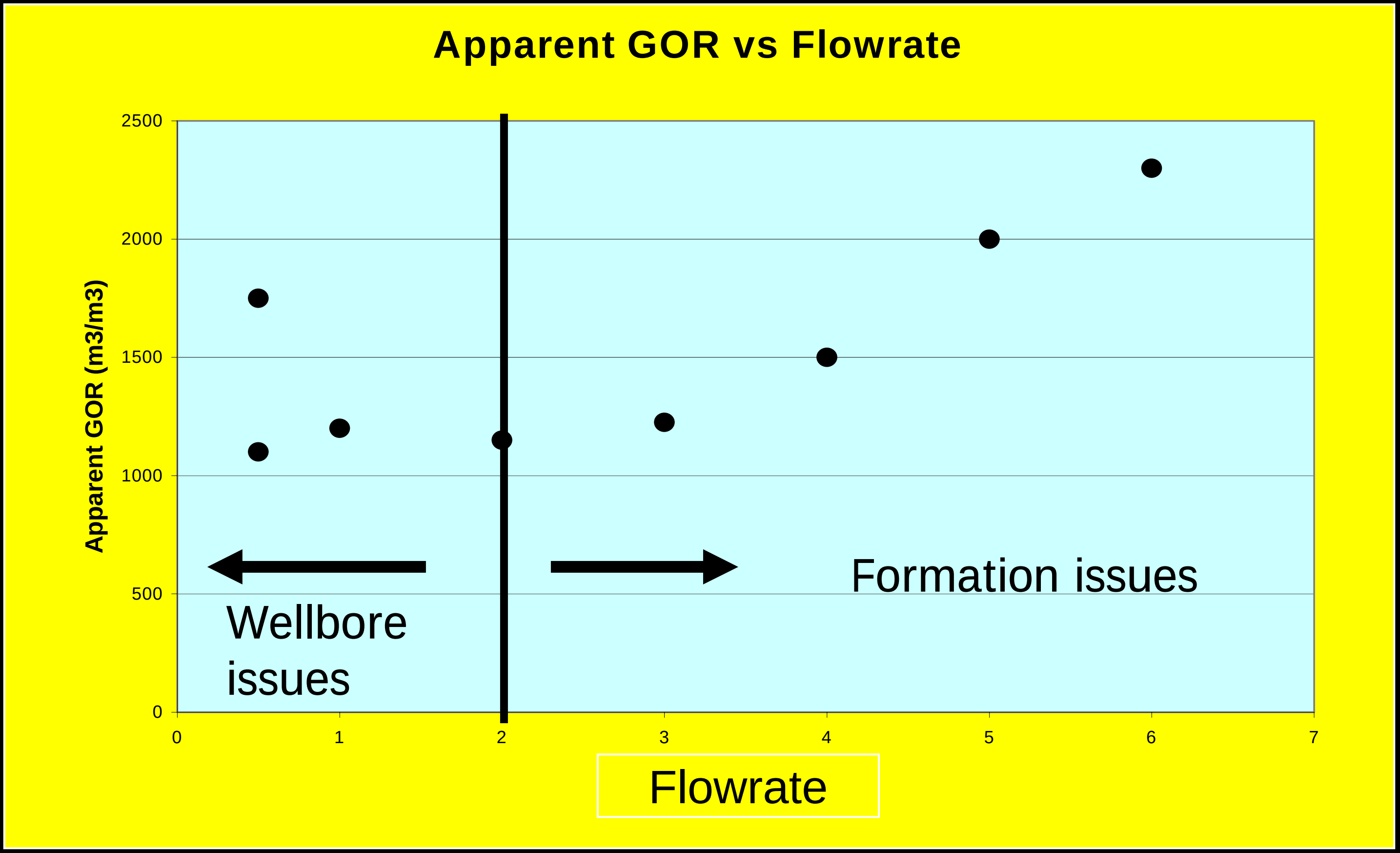
1. Pitfalls to Avoid in Sampling Condensate wells
2. Characterization of Gas Condensate Fluids
3. Production Considerations
4. Performance Optimization

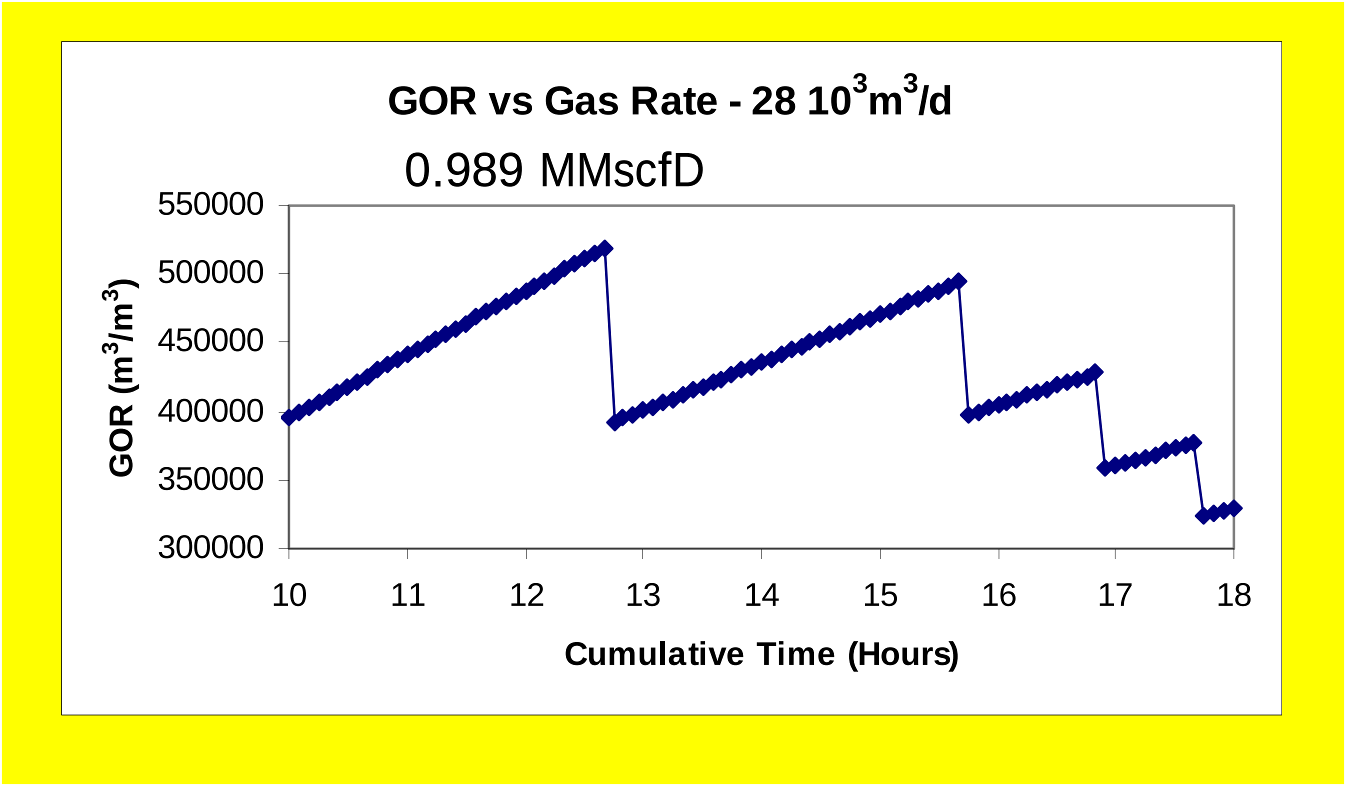
Standard Technique:

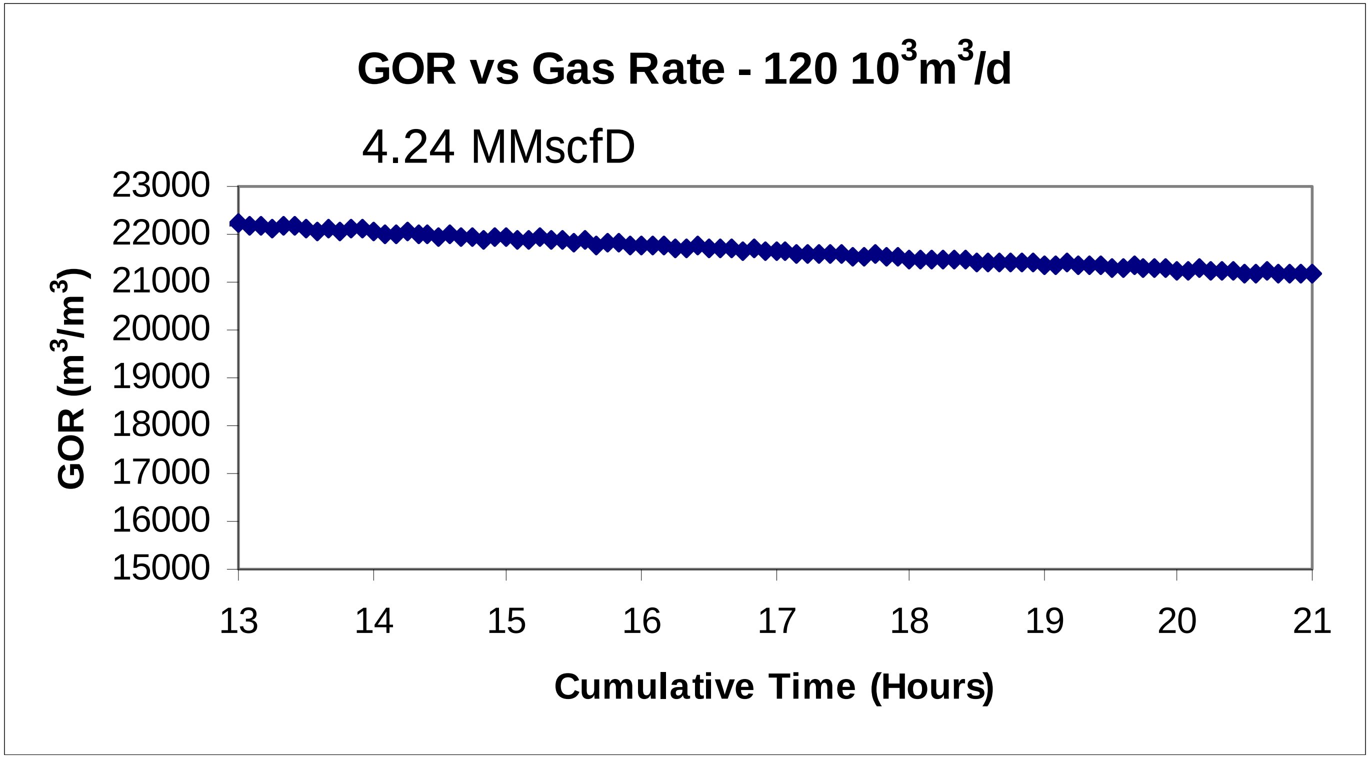
1. Allow the well to clean up.
2. Flow at a low rate (lowest drawdown where stability is maintained). Capture liquid and gas samples.
3. Flow at a higher rate – capture liquid and gas samples.
4. Beneficial to obtain samples for **at least** three rates.

Stable flow rate and GOR are necessary conditions for sampling.

As a general expectation -

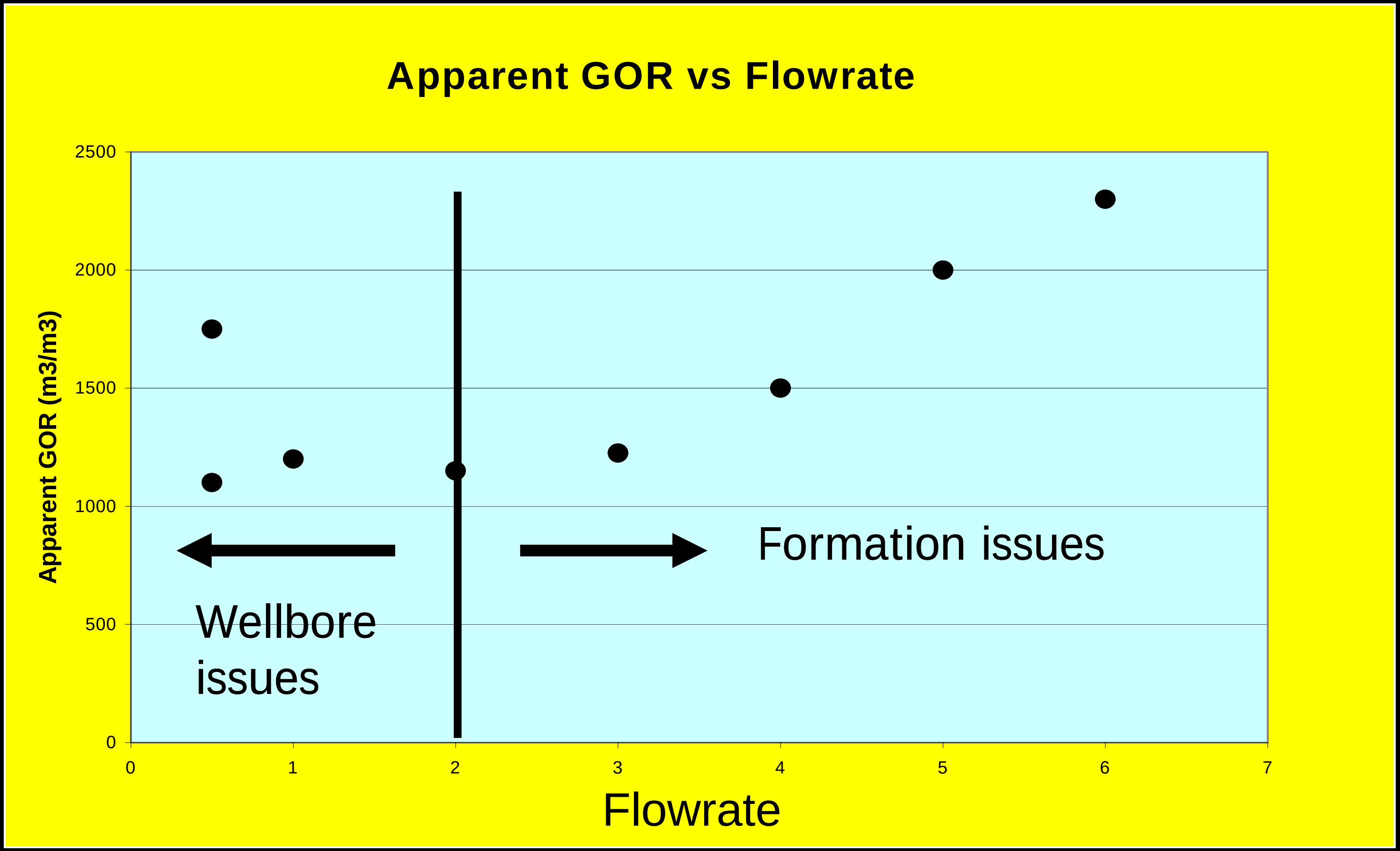


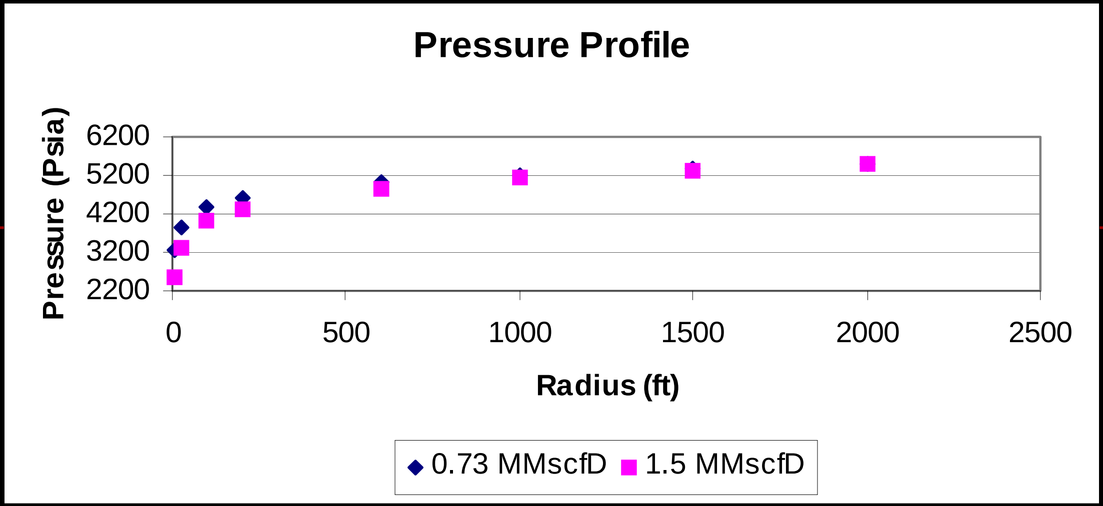

GOR vs Gas Rate - 28 10³m³/d
0.989 MMscfD
GOR (m³/m³)
550000
500000
450000
400000
350000
300000
10
11
12
13
14
15
16
17
18
Cumulative Time (Hours)



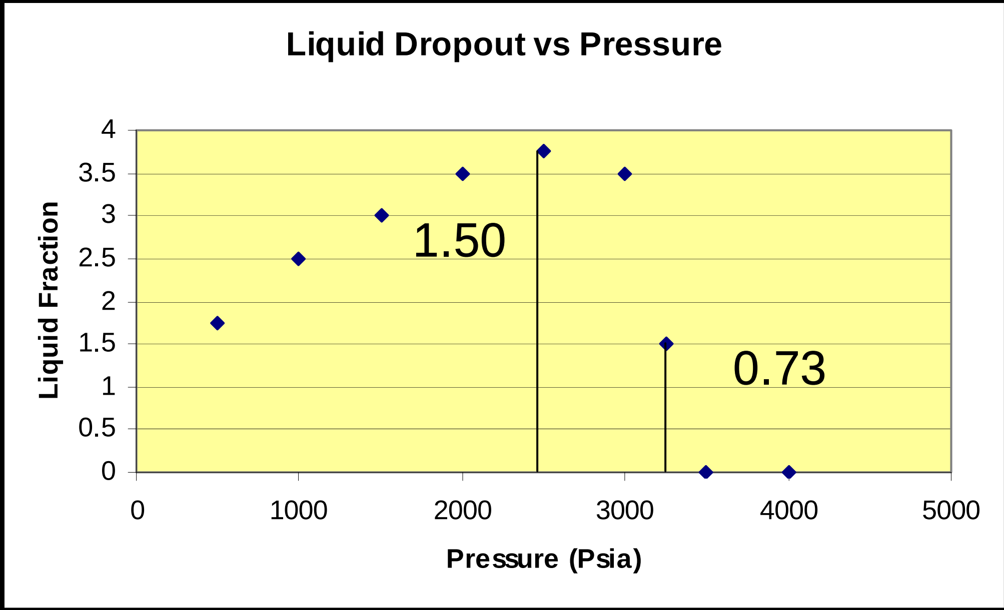
GOR vs Gas Rate - 120 10³m³/d
4.24 MMscfD
GOR (m³/m³)
23000
22000
21000
20000
19000
18000
17000
16000
15000
13
14
15
16
17
18
19
20
21
Cumulative Time (Hours)

As a general expectation -





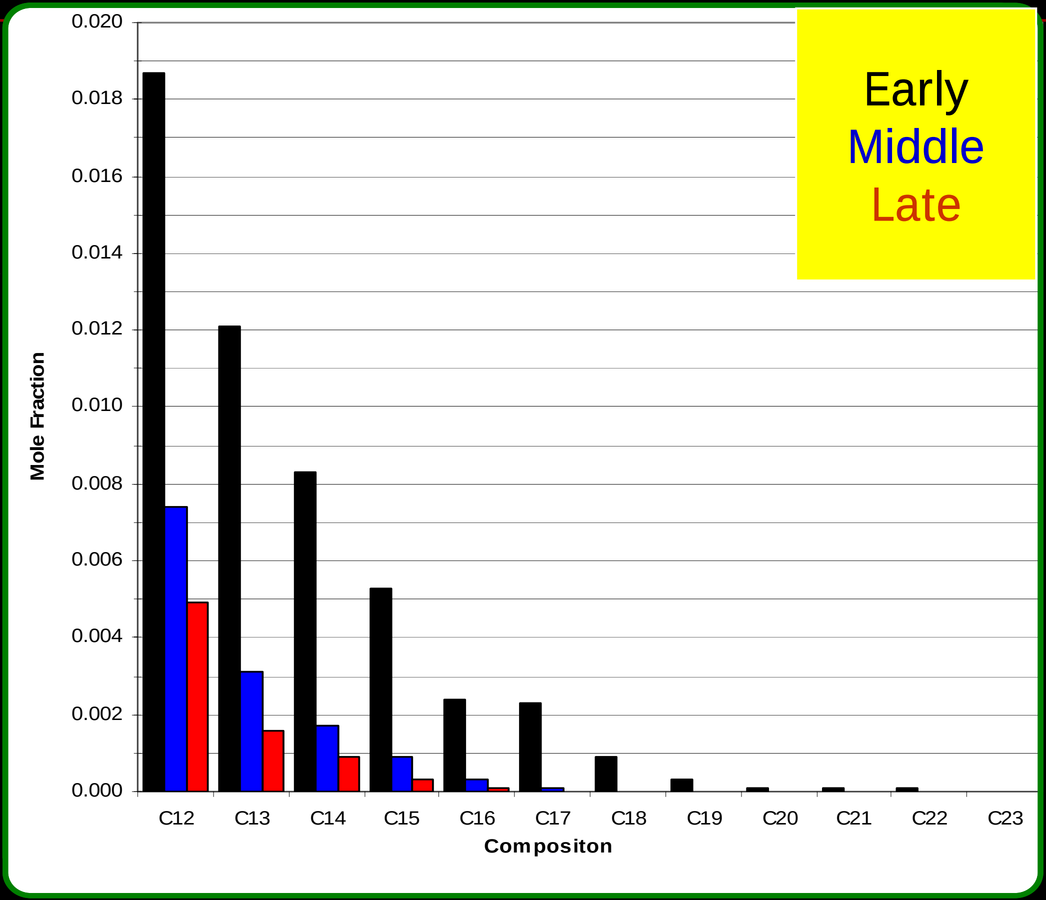
Pressure Profile
Pressure (Psia)
6200
5200
4200
3200
2200
0
500
1000
1500
2000
2500
Radius (ft)
0.73 MMscfD
1.5 MMscfD



Liquid Dropout vs Pressure
Liquid Fraction
4
3.5
3
2.5
2
1.5
1
0.5
0
1.50
0.73
0
1000
2000
3000
4000
5000
Pressure (Psia)

In addition to liquid volume, look at heavier ends -

The heavier ends are already gone!



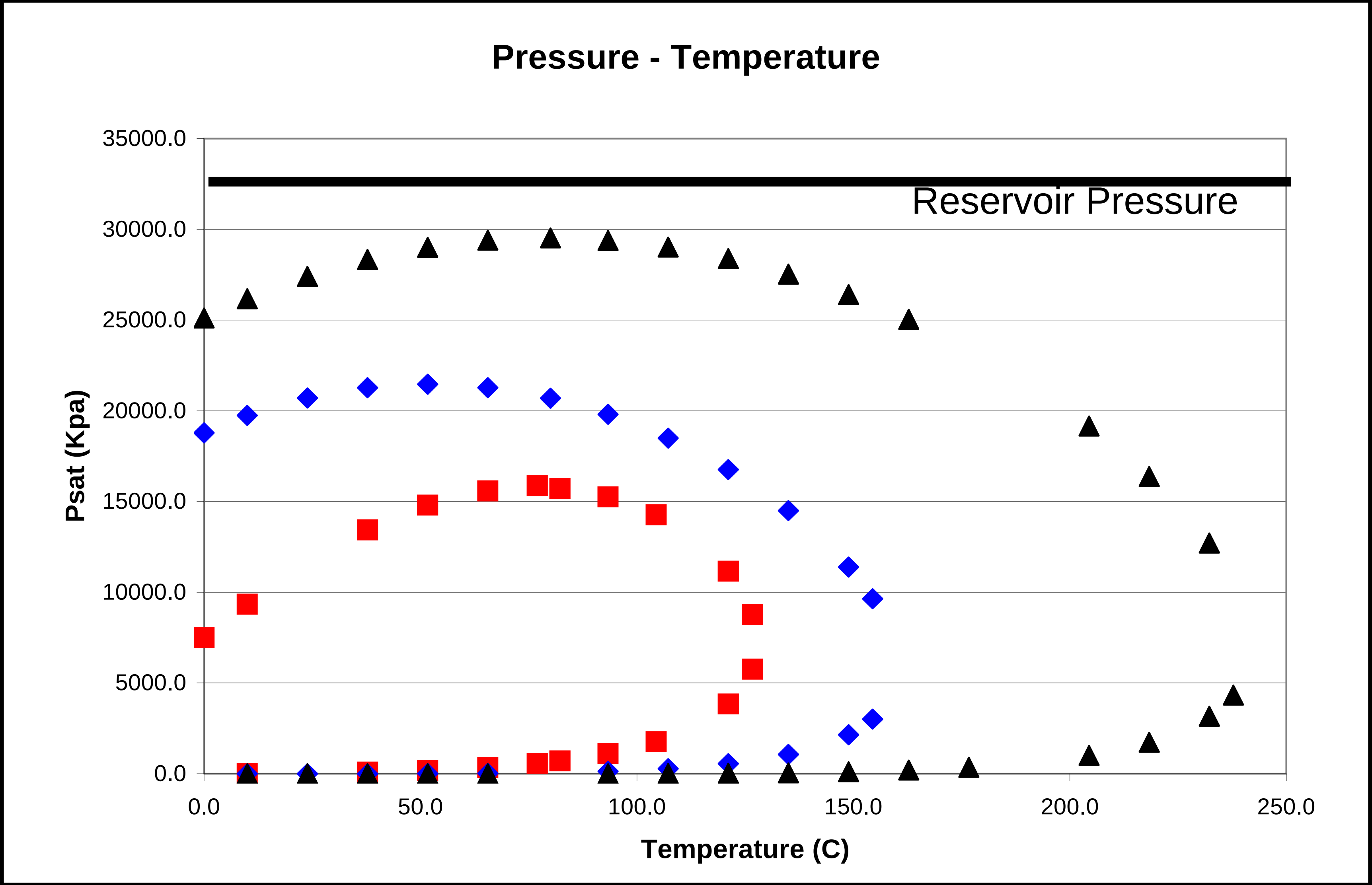
Impact on composition is significant.

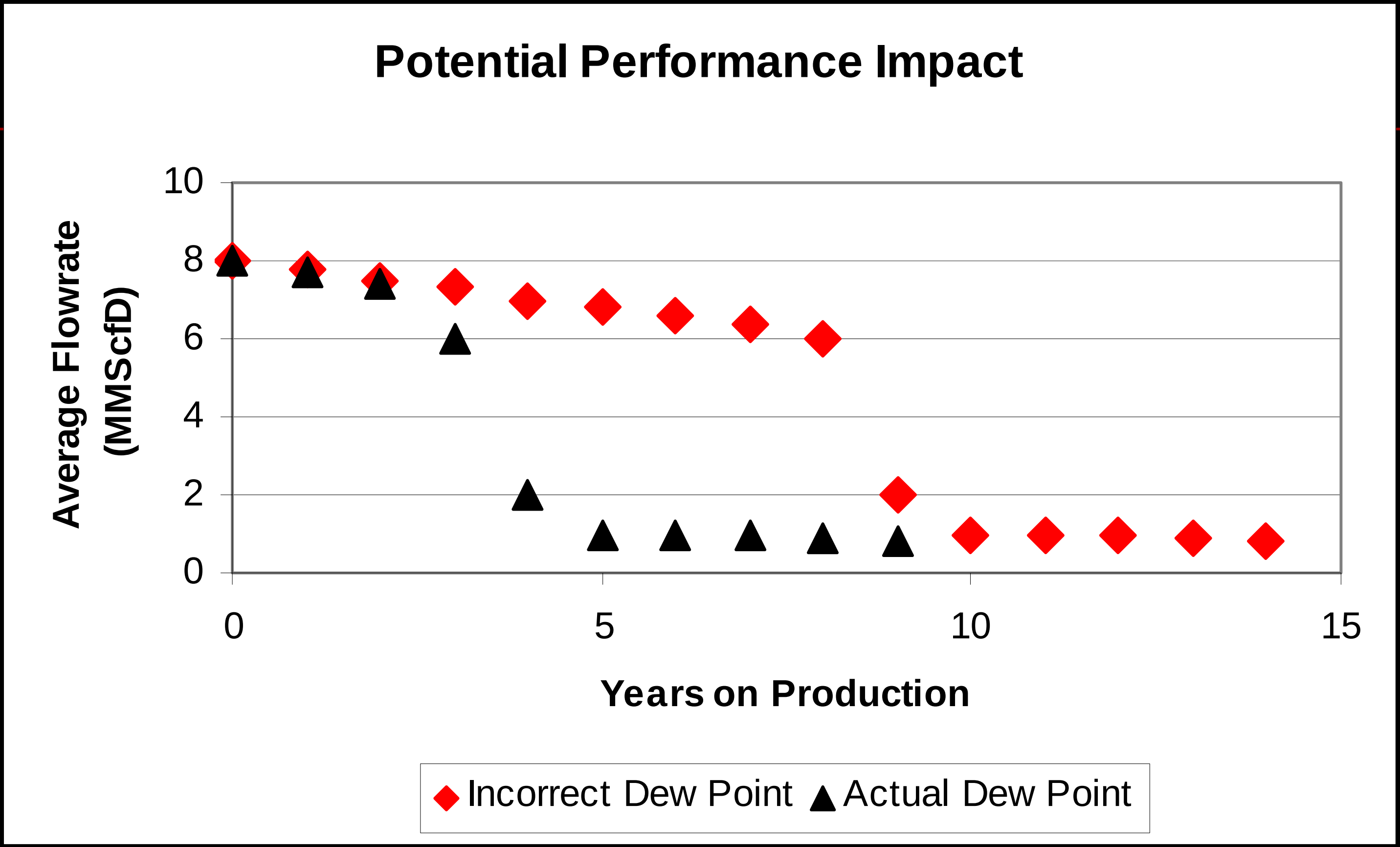
-Liquids condense from the gas

-liquids accumulate in the formation.

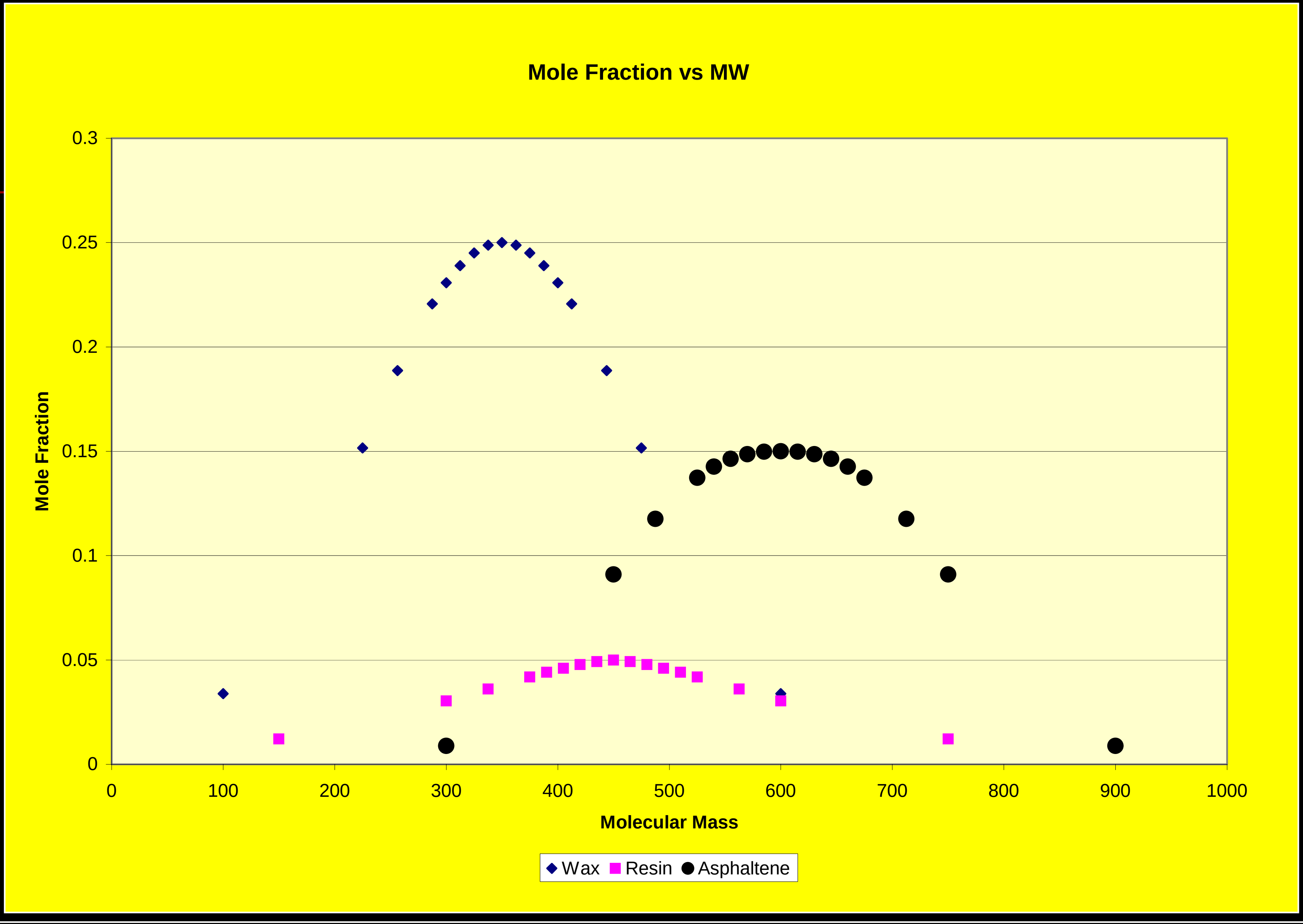
-surface liquid is apparently lighter (less heavy ends).

The result – lower apparent dew point pressure and lower apparent liquid yield.


Pressure - Temperature
Reservoir Pressure
Psat (Kpa)
35000.0
30000.0
25000.0
20000.0
15000.0
10000.0
5000.0
0.0
0.0
50.0
100.0
150.0
200.0
250.0
Temperature (C)

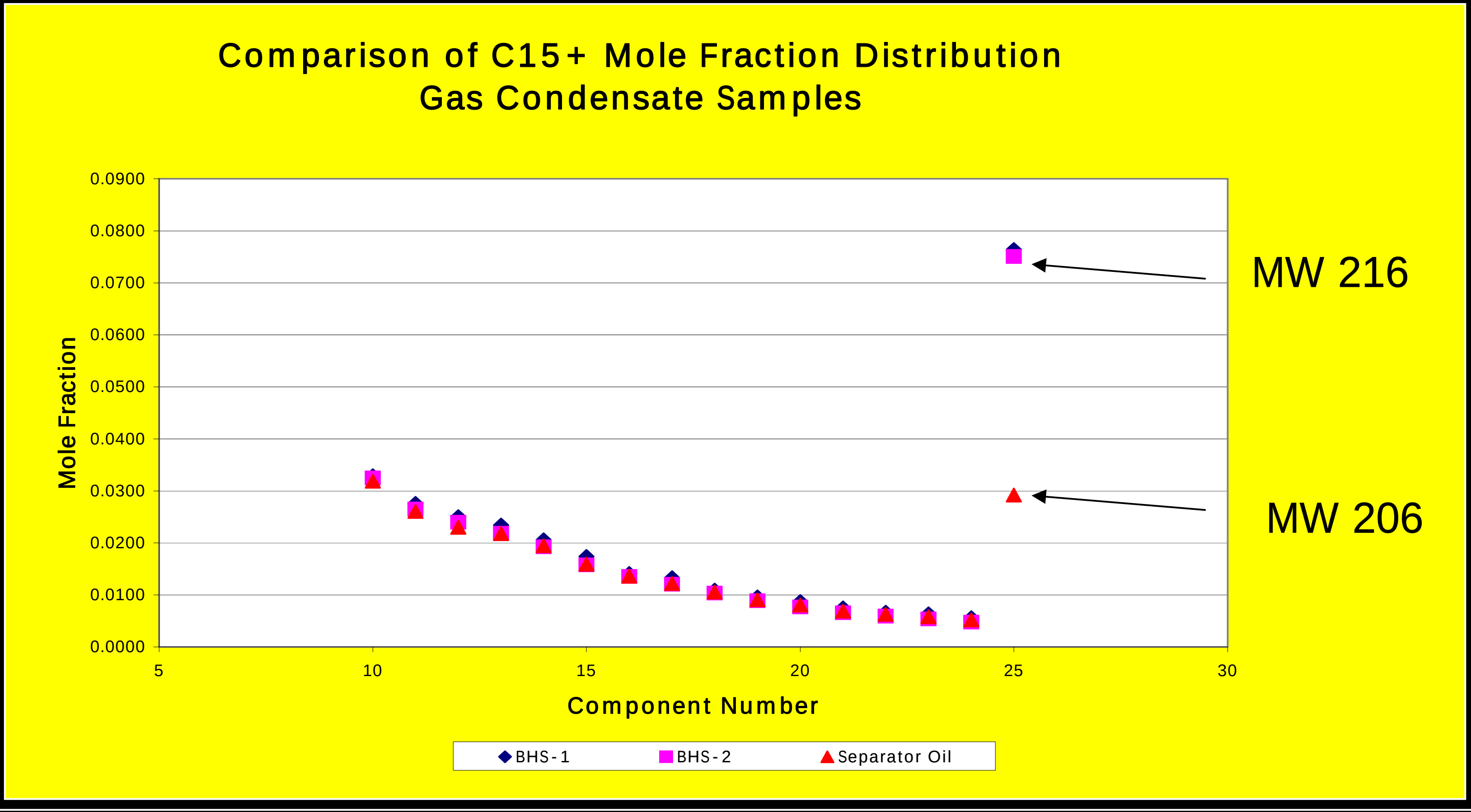


Potential Performance Impact
Average Flowrate (MMScfD)
10
8
6
4
2
0
0
5
10
15
Years on Production
Incorrect Dew Point
Actual Dew Point



Mole Fraction vs MW
Mole Fraction
0.3
0.25
0.2
0.15
0.1
0.05
0
0
100
200
300
400
500
600
700
800
900
1000
Molecular Mass
Wax
Resin
Asphaltene

For example:



Comparison of C15+ Mole Fraction Distribution
Gas Condensate Samples
0.0900
0.0800
0.0700
0.0600
0.0500
0.0400
0.0300
0.0200
0.0100
0.0000
Mole Fraction
5
10
15
20
25
30
Component Number
BHS-1
BHS-2
Separator Oil
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

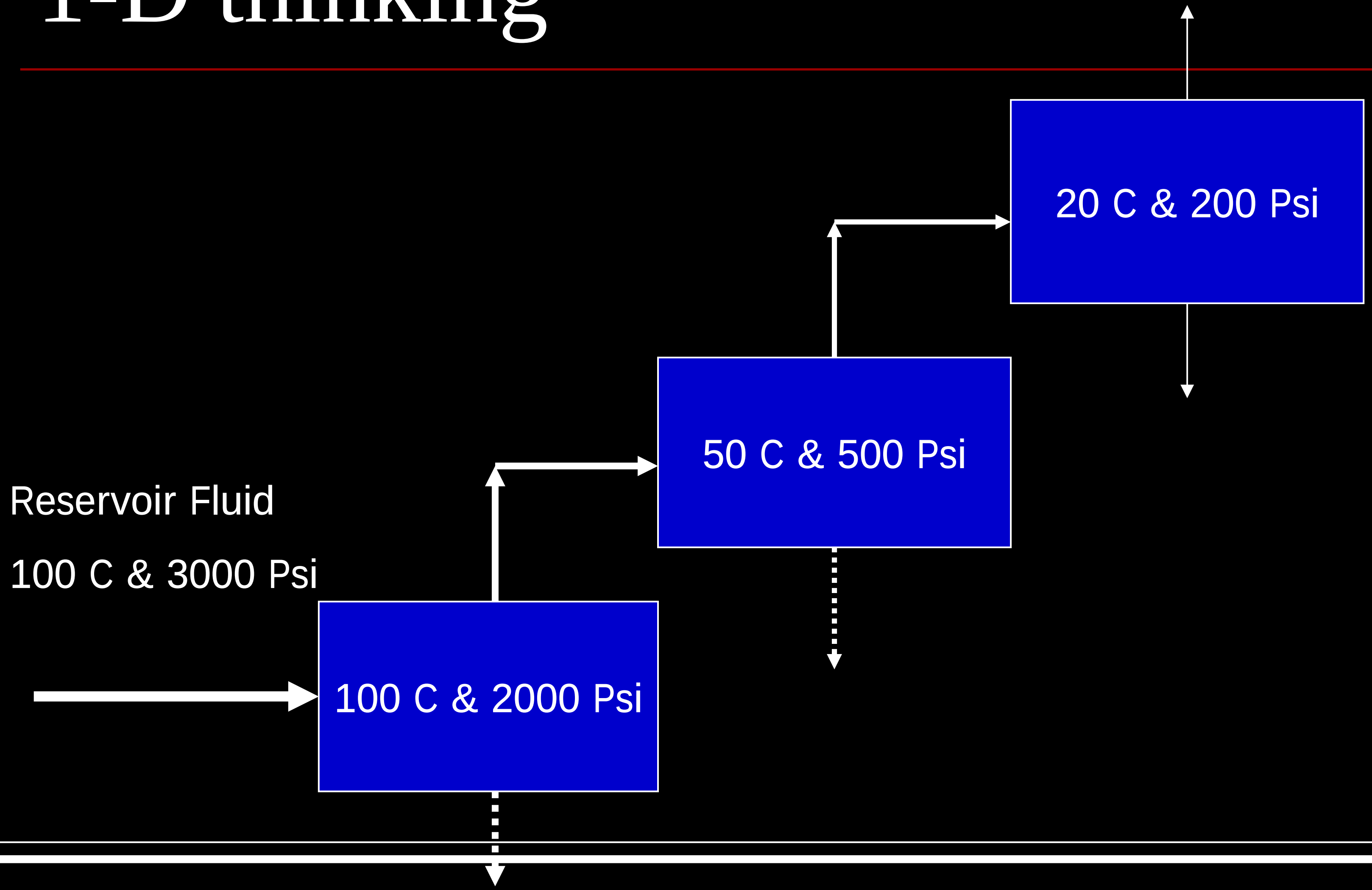
2. If any appearance of solids obtain BHS for reference on C12+.

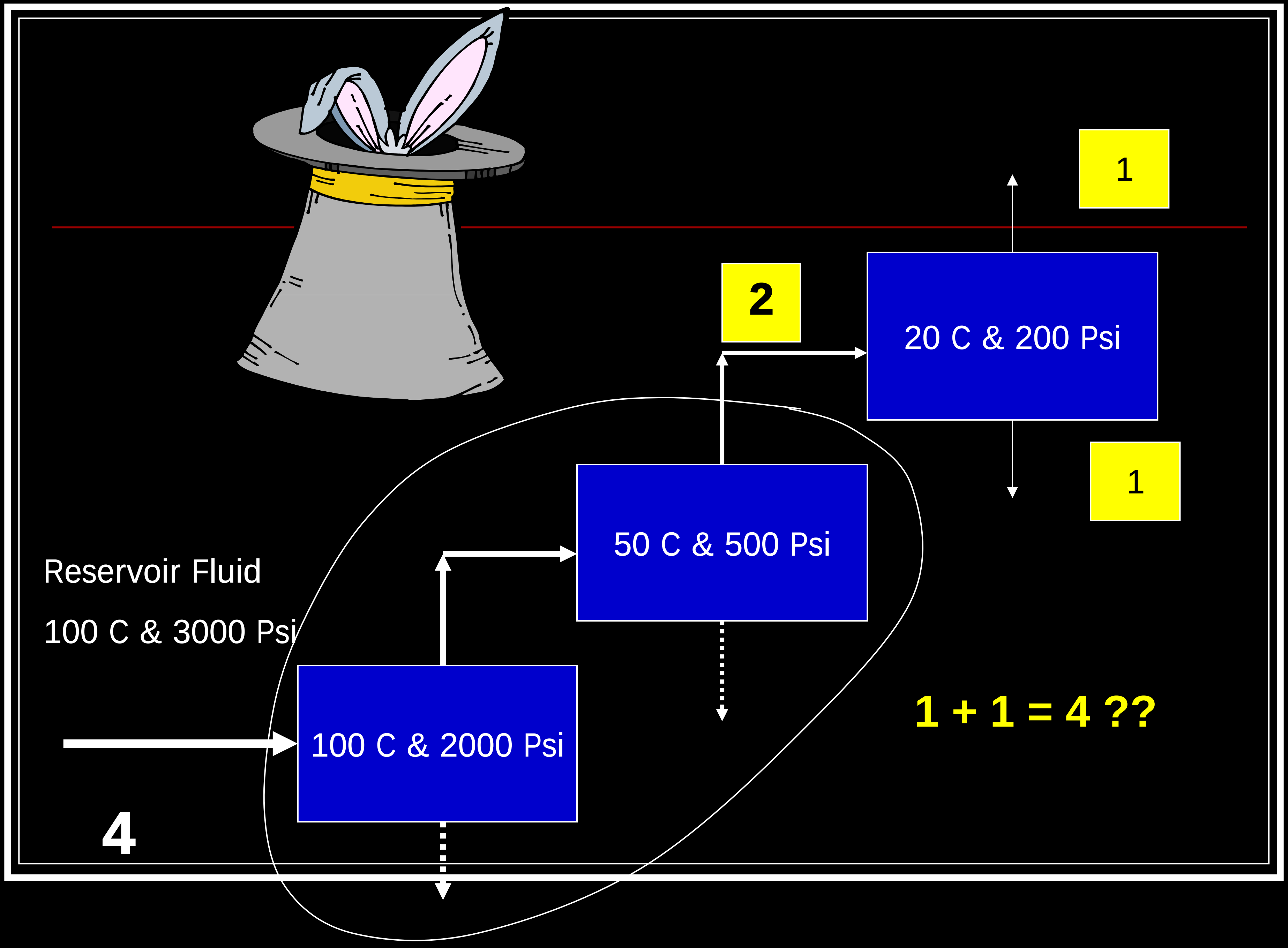
3. Sample early in the life of the well/reservoir.

Presentation Outline

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

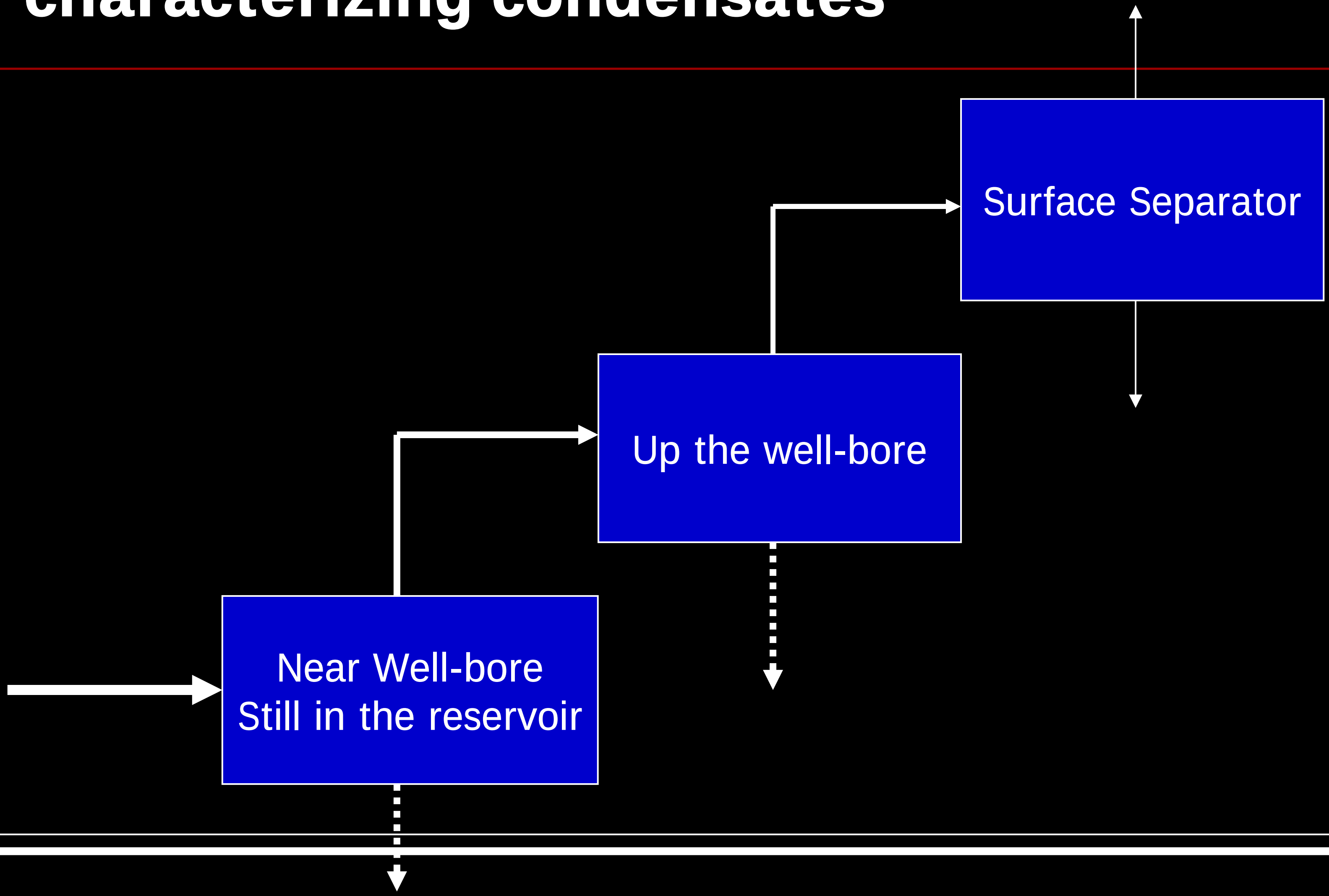
1-D thinking


Reservoir Fluid
100 C & 3000 Psi
100 C & 2000 Psi
50 C & 500 Psi
20 C & 200 Psi

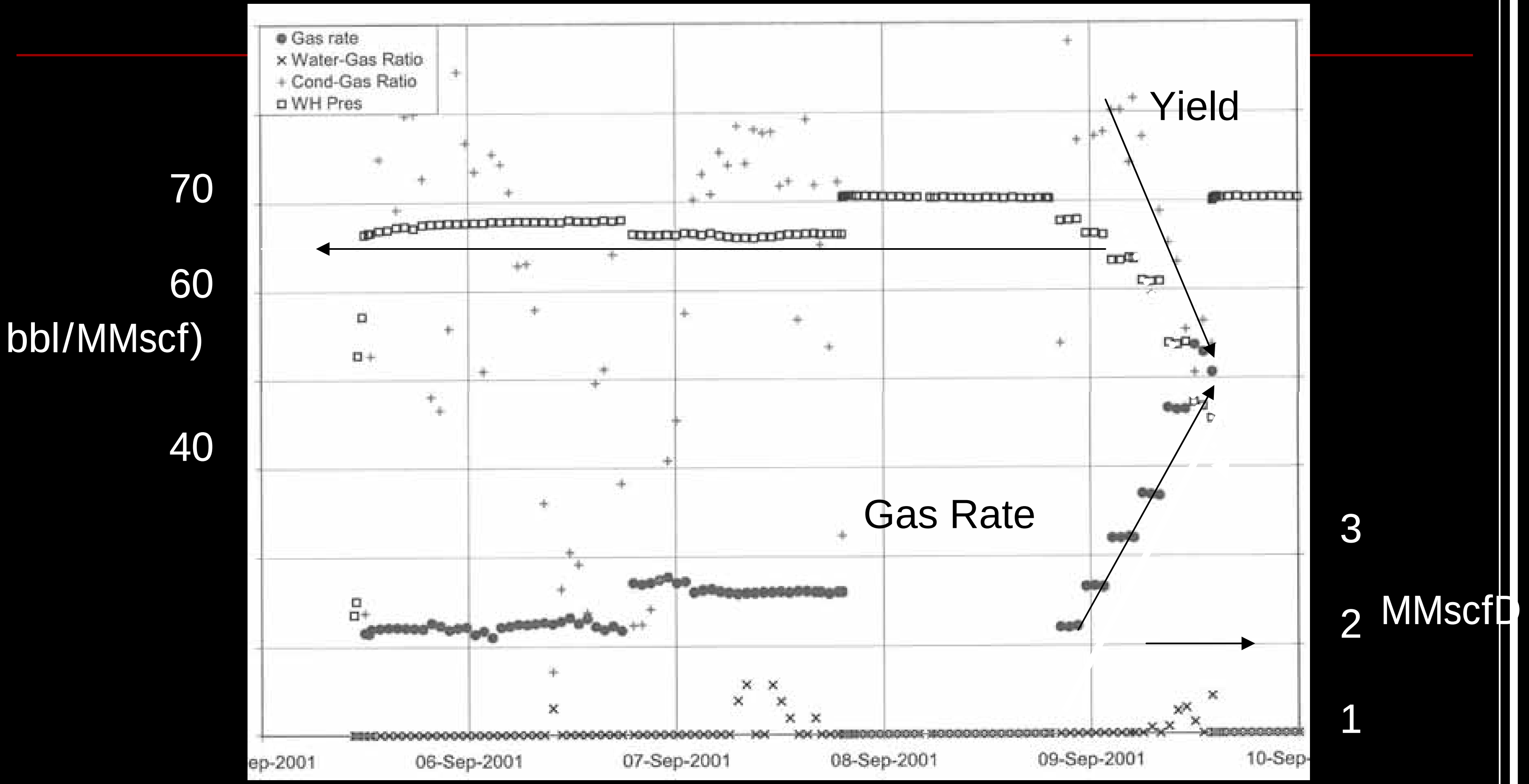


Reservoir Fluid
100 C & 3000 Psi
100 C & 2000 Psi
50 C & 500 Psi
20 C & 200 Psi
2
1
1
1 + 1 = 4 ??
4

We do it all the time in characterizing condensates



For example -


70
60
bbl/MMscf)
40
Gas rate
Water-Gas Ratio
Cond-Gas Ratio
WH Pres
Yield
Gas Rate
3
2
MMscfD
1
ep-2001
06-Sep-2001
07-Sep-2001
08-Sep-2001
09-Sep-2001
10-Sep-

Conclusion of the evaluation engineers -

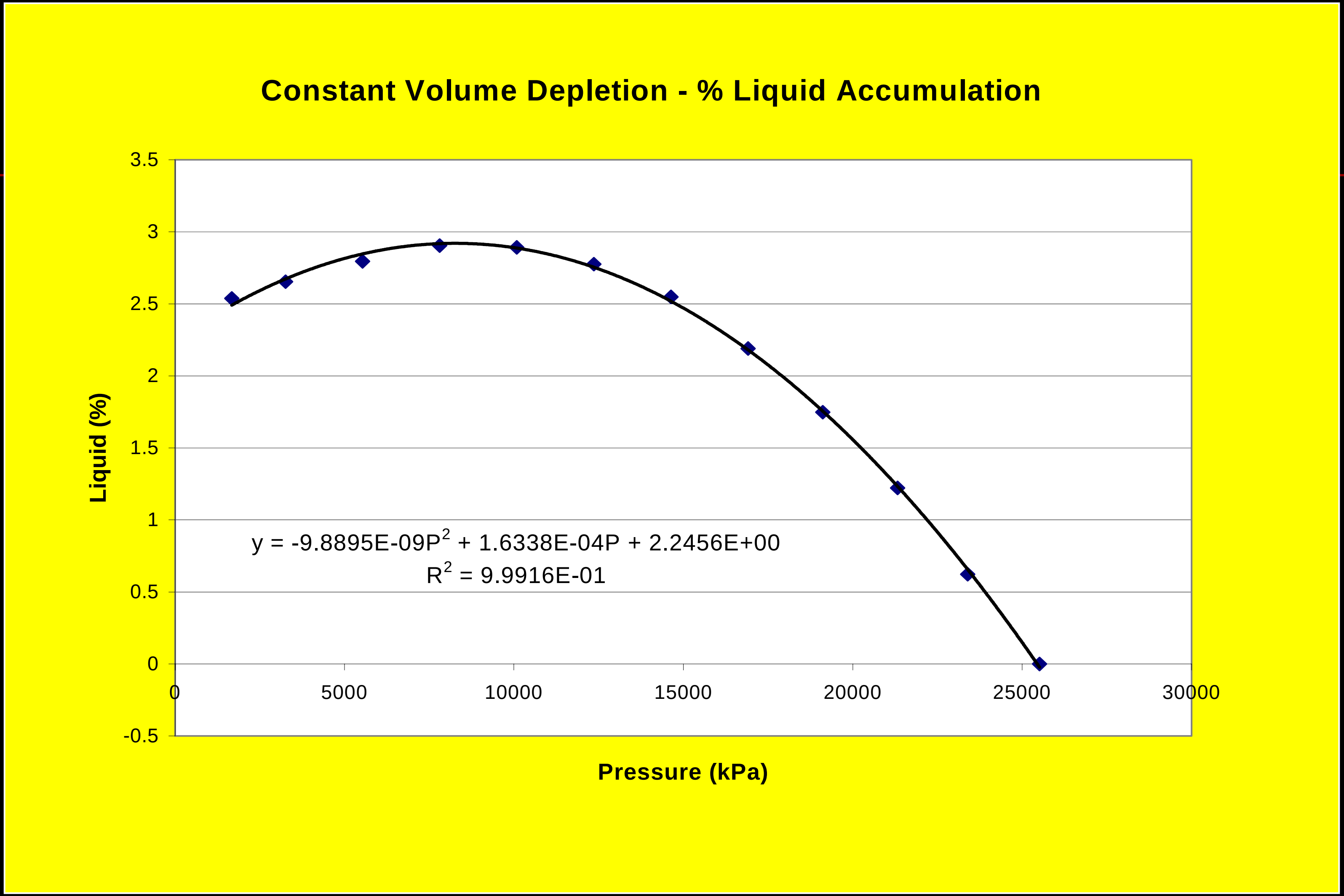
-liquid yield was only 22.7 bbl/MMscf

-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
Liquid (%)
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
0
5000
10000
15000
20000
25000
30000
y = -9.8895E-09P2 + 1.6338E-04P + 2.2456E+00
R2 = 9.9916E-01
Pressure (kPa)

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

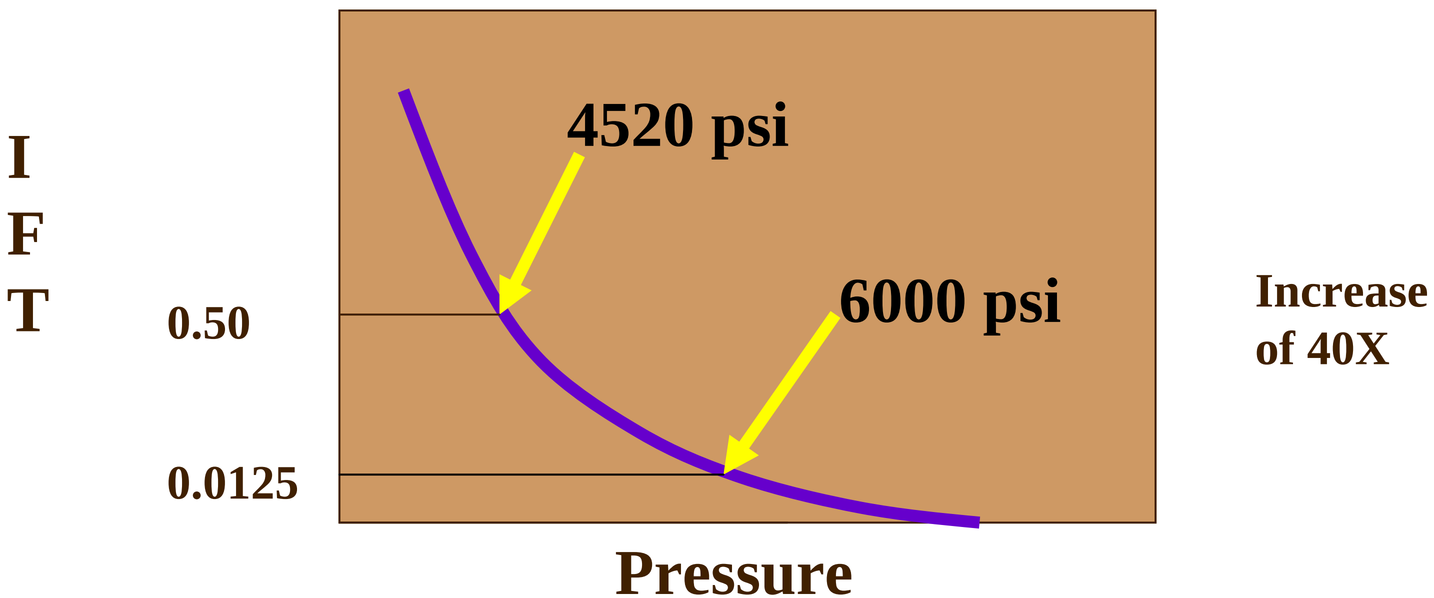
$$\Delta P \quad \alpha \quad IFT/D$$

- IFT increases as Pressure decreases

- At lower pressures, greater ΔP will be required to produce similar flow rates.

IFT may increase very rapidly with decreasing Pressure.

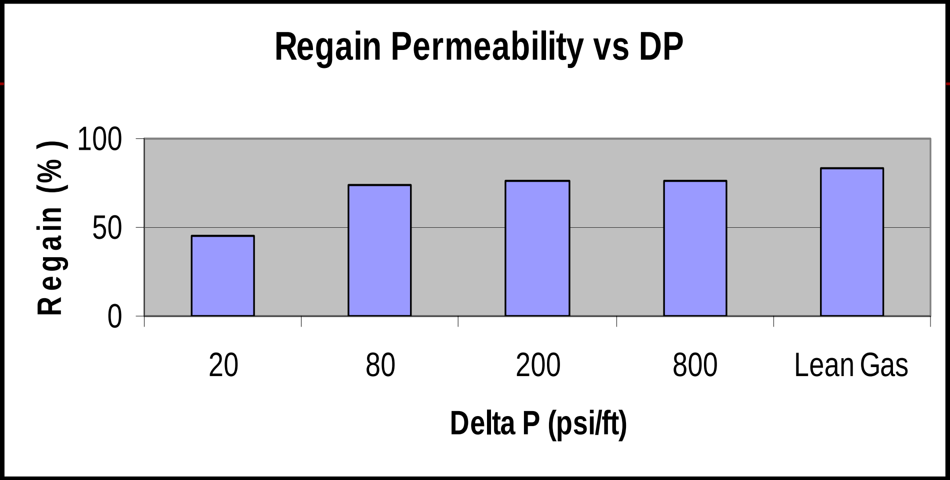
$$P_{CAP} \quad \alpha \quad \frac{\sigma}{D}$$



Bigger pump may be counter-effective!

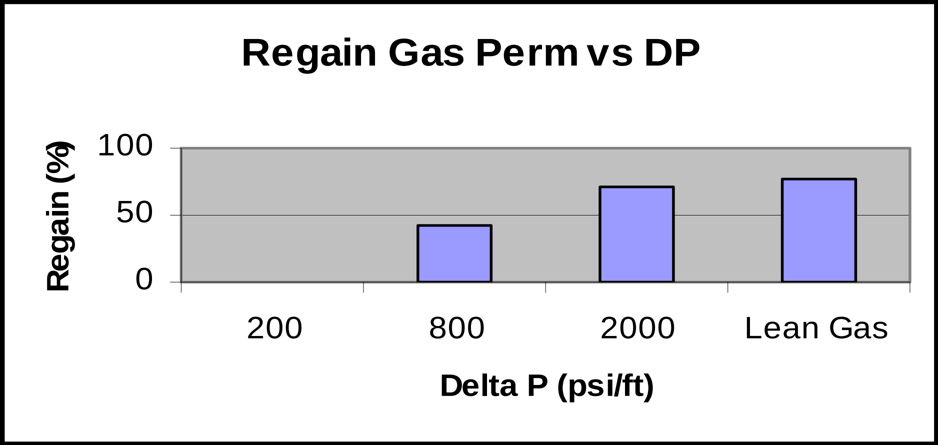
20684 kPa

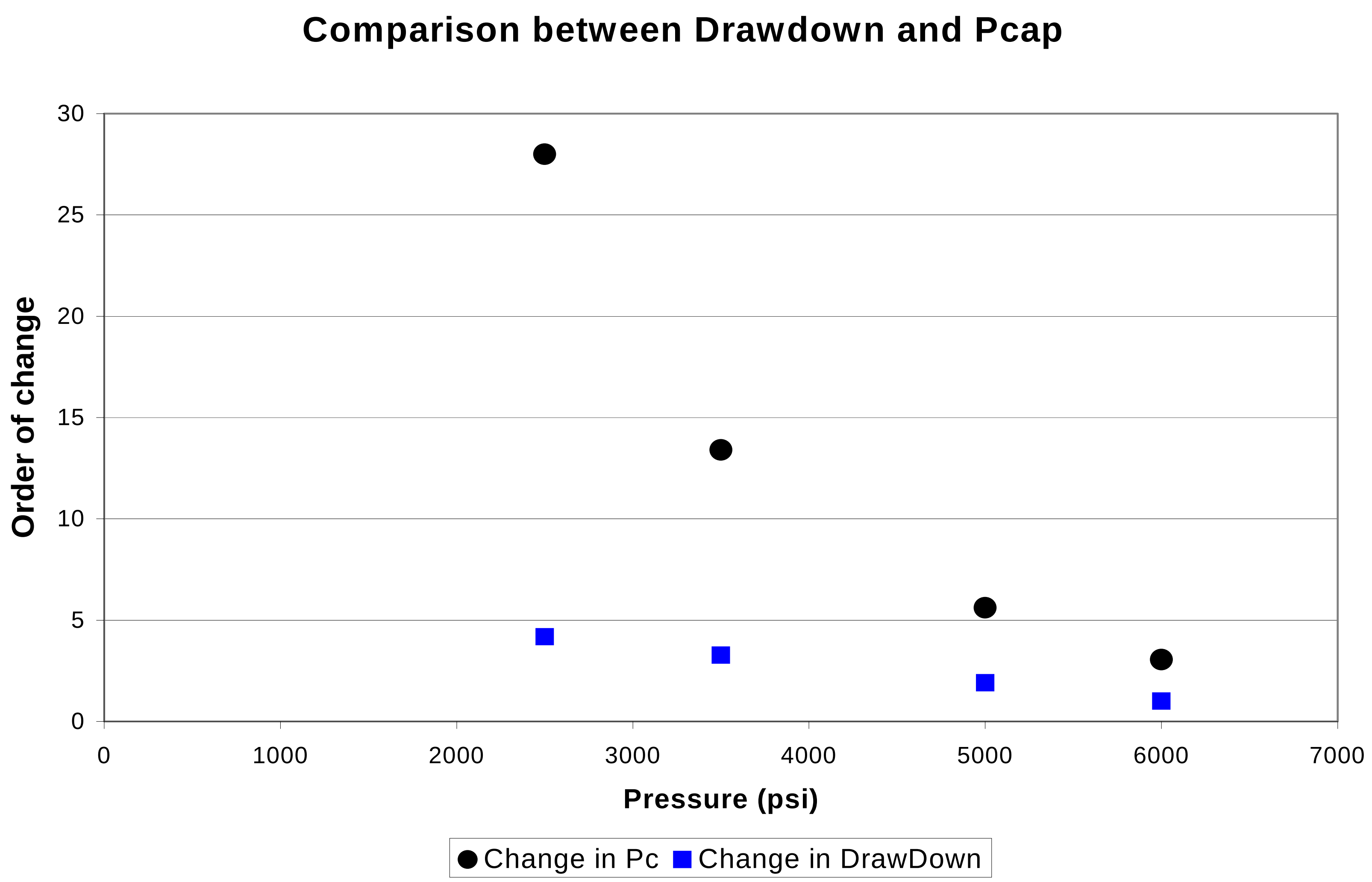
(3000 Psia)

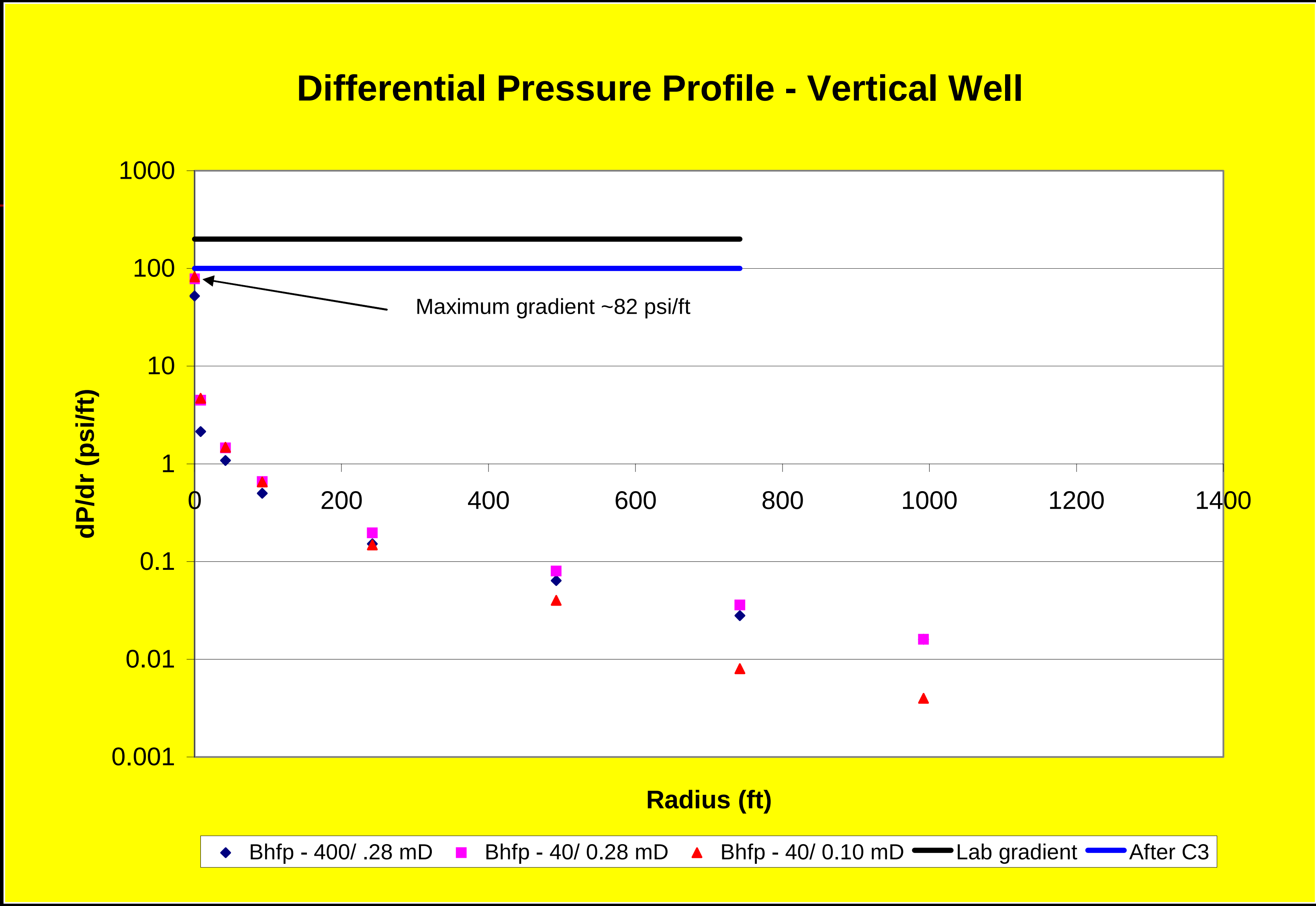


13789 kPa

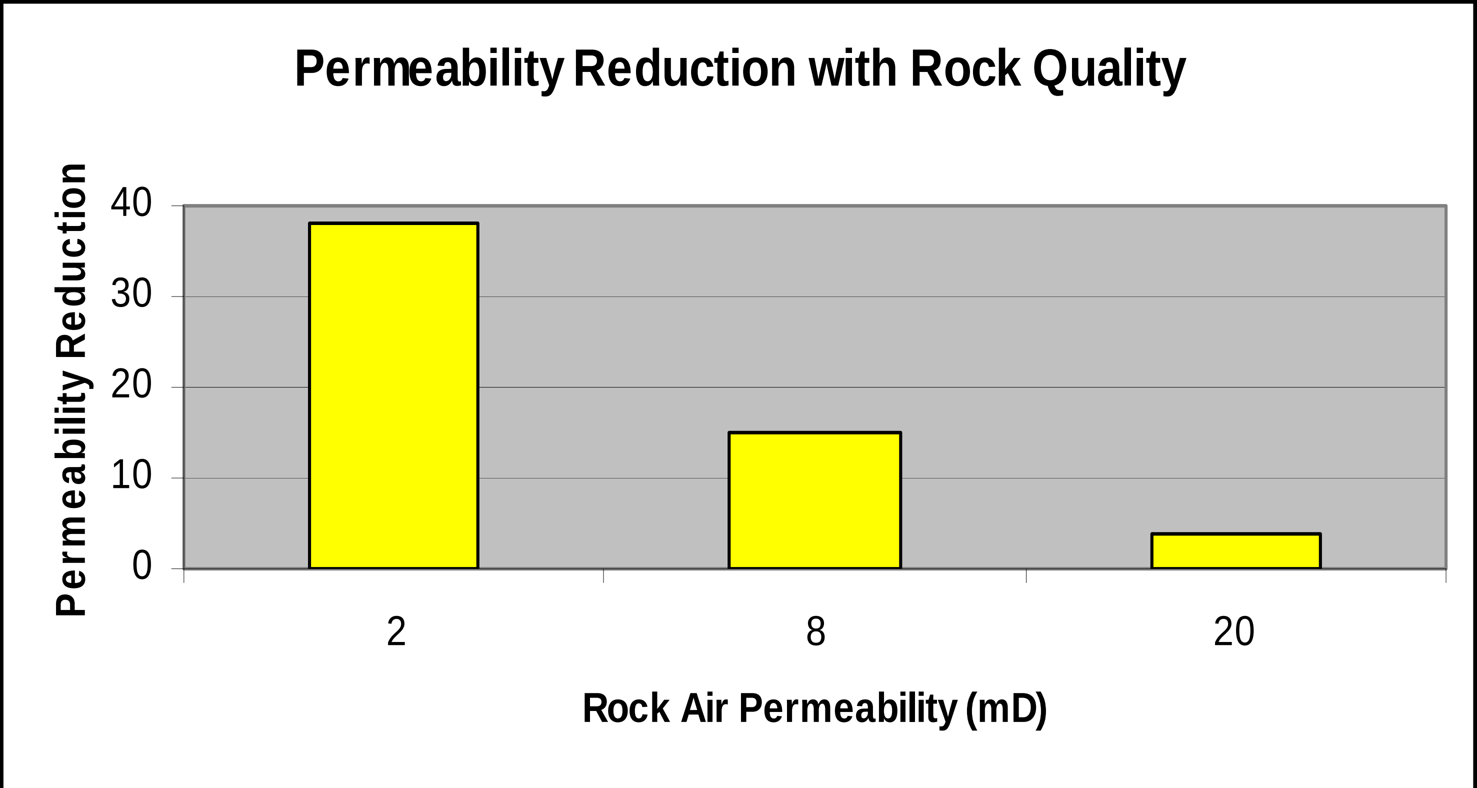
2000 Psia



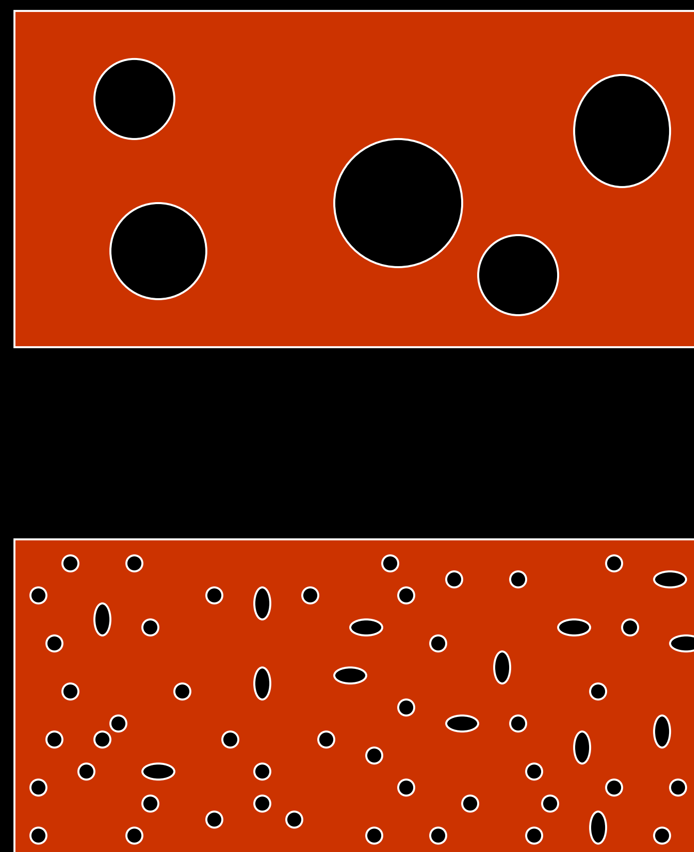

Comparison between Drawdown and Pcap
Order of change
30
25
20
15
10
5
0
0
1000
2000
3000
4000
5000
6000
7000
Pressure (psi)
Change in Pc
Change in DrawDown


Differential Pressure Profile - Vertical Well
1000
100
10
1
0.1
0.01
0.001
dP/dr (psi/ft)
0
200
400
600
800
1000
1200
1400
Radius (ft)
Maximum gradient ~82 psi/ft
Bhfp - 400/ .28 mD
Bhfp - 40/ 0.28 mD
Bhfp - 40/ 0.10 mD
Lab gradient
After C3

2. Porous Feature Size Effects



Beware!



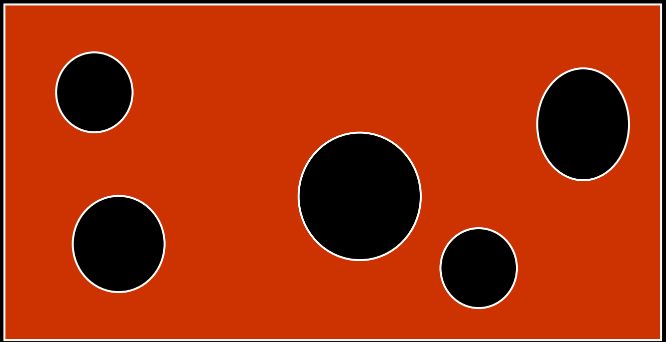
Example:

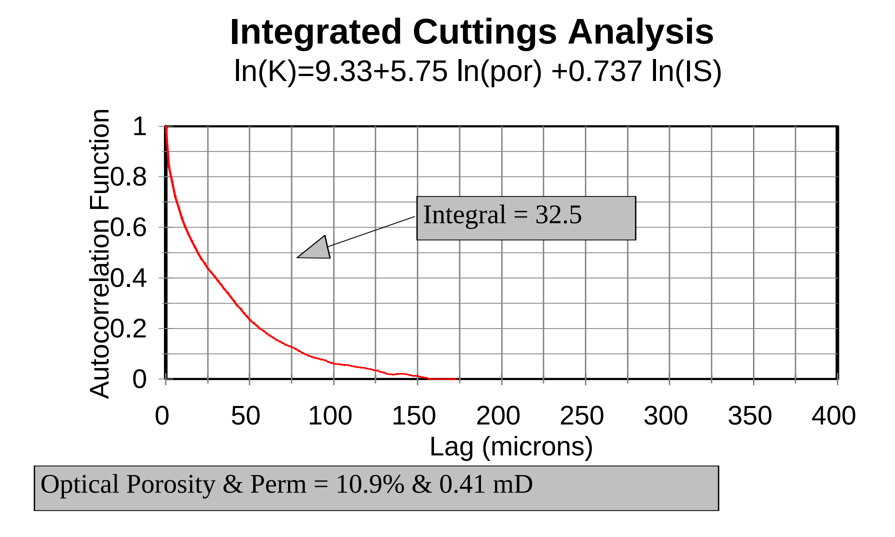
Core 1 had a permeability of 256 mD, ☠=17.4%.

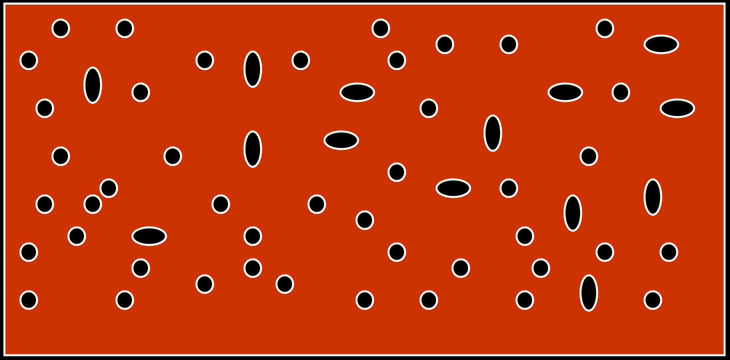
Core 2 had a permeability of 39 mD, ☠=18.5 %.

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(por) +0.737 ln(IS)
Autocorrelation Function
1
0.8
0.6
0.4
0.2
0
0
50
100
150
200
250
300
350
400
Lag (microns)
Integral = 32.5
Optical Porosity & Perm = 10.9% & 0.41 mD



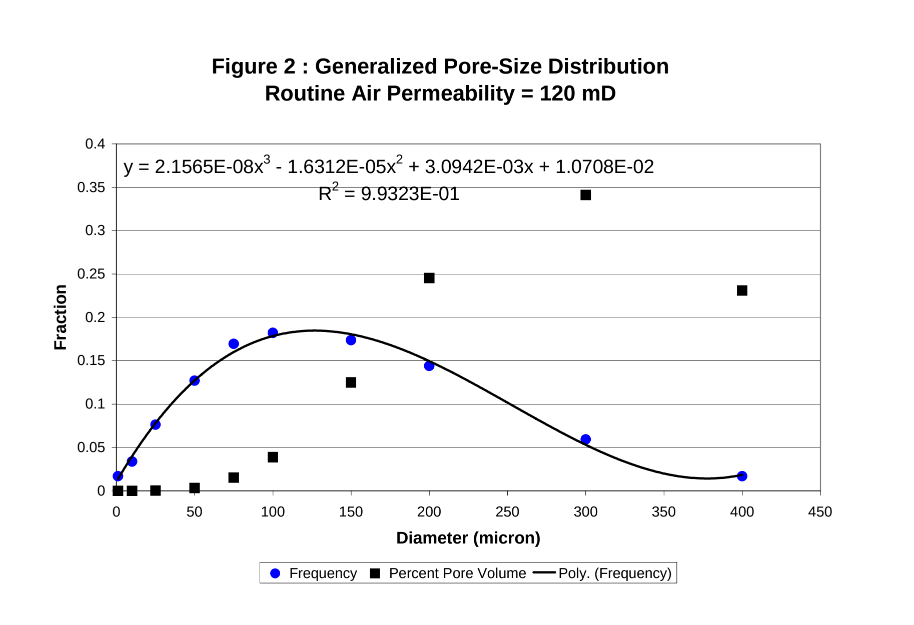


Figure 2 : Generalized Pore-Size Distribution
Routine Air Permeability = 120 mD
y = 2.1565E-08x3 - 1.6312E-05x2 + 3.0942E-03x + 1.0708E-02
R2 = 9.9323E-01
Fraction
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
50
100
150
200
250
300
350
400
450
Diameter (micron)
Frequency
Percent Pore Volume
Poly. (Frequency)

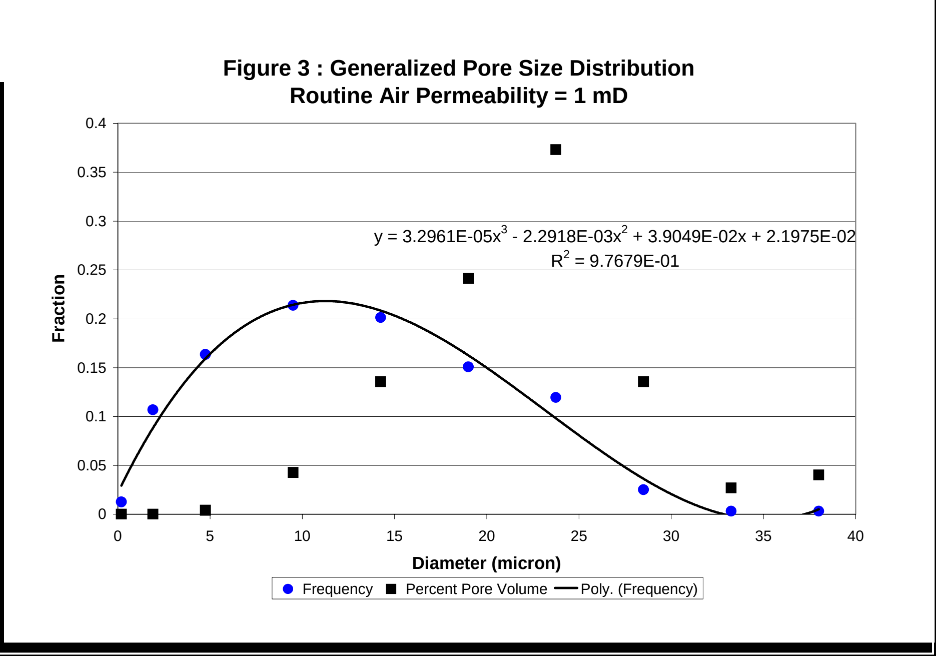
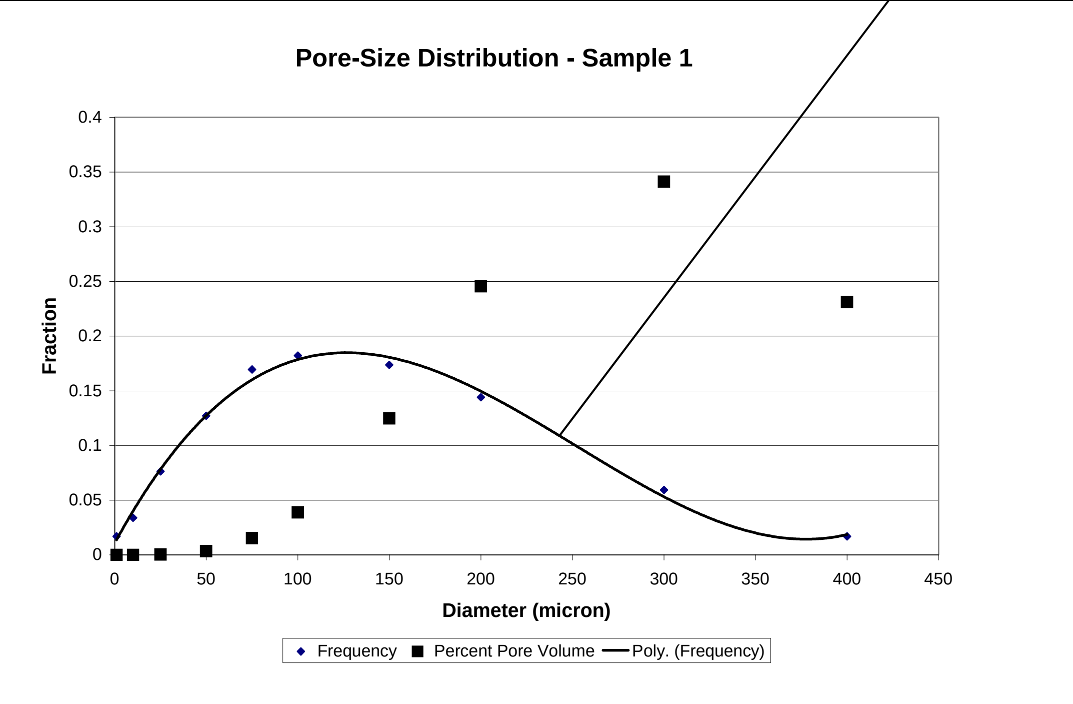


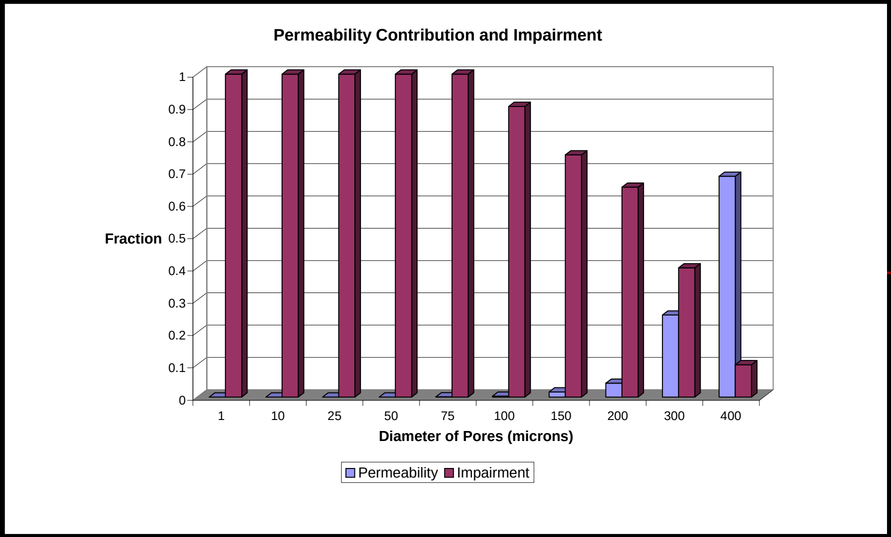
Figure 3 : Generalized Pore Size Distribution
Routine Air Permeability = 1 mD
y = 3.2961E-05x3 - 2.2918E-03x2 + 3.9049E-02x + 2.1975E-02
R2 = 9.7679E-01
Fraction
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
5
10
15
20
25
30
35
40
Diameter (micron)
Frequency
Percent Pore Volume
Poly. (Frequency)

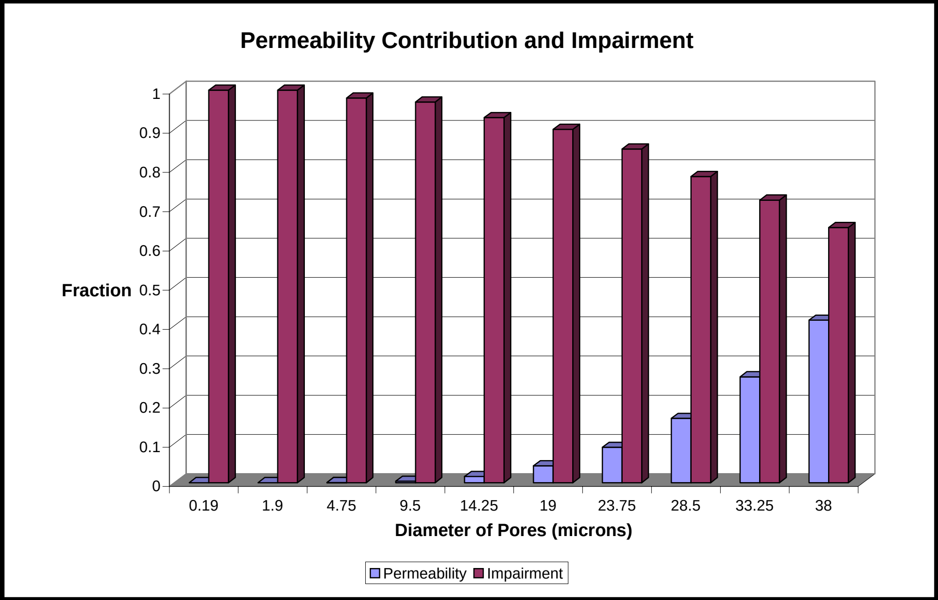
If we only knew exactly how flow changes:

$$dQ = \frac{\Delta P}{\mu L} \int_{O}^{R_{Max}} K(r) f(r) 2\pi r dr$$



Assume $K(r) = r^2$


Permeability Contribution and Impairment
Fraction
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
10
25
50
75
100
150
200
300
400
Diameter of Pores (microns)
Permeability
Impairment


Permeability Contribution and Impairment
Fraction
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.19
1.9
4.75
9.5
14.25
19
23.75
28.5
33.25
38
Diameter of Pores (microns)
Permeability
Impairment

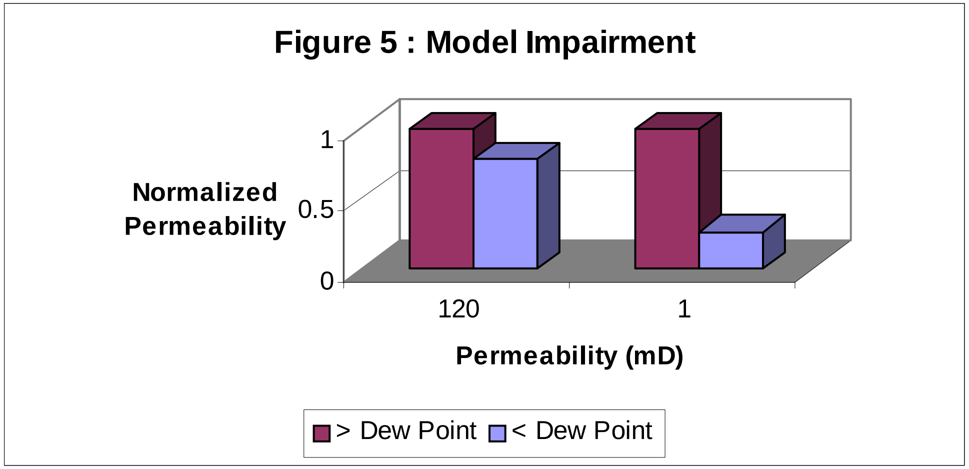


Figure 5 : Model Impairment
Normalized Permeability
1
0.5
0
120
1
Permeability (mD)
> Dew Point
< Dew Point

Presentation Outline

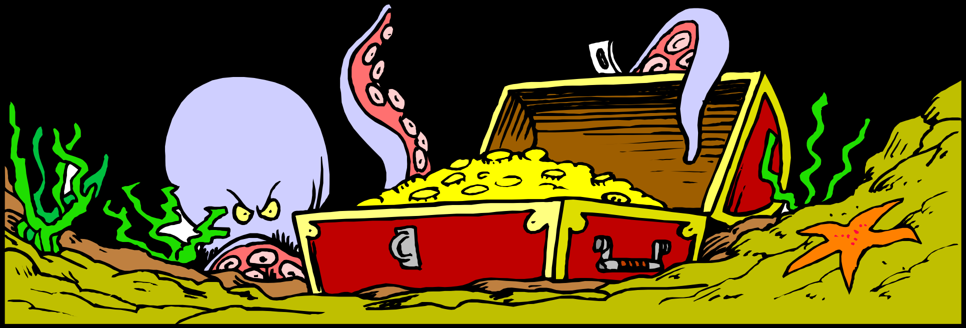
1. Pitfalls to Avoid in Sampling Condensate wells
2. Characterization of Gas Condensate Fluids
3. Production Considerations
4. **Performance Optimization**

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?



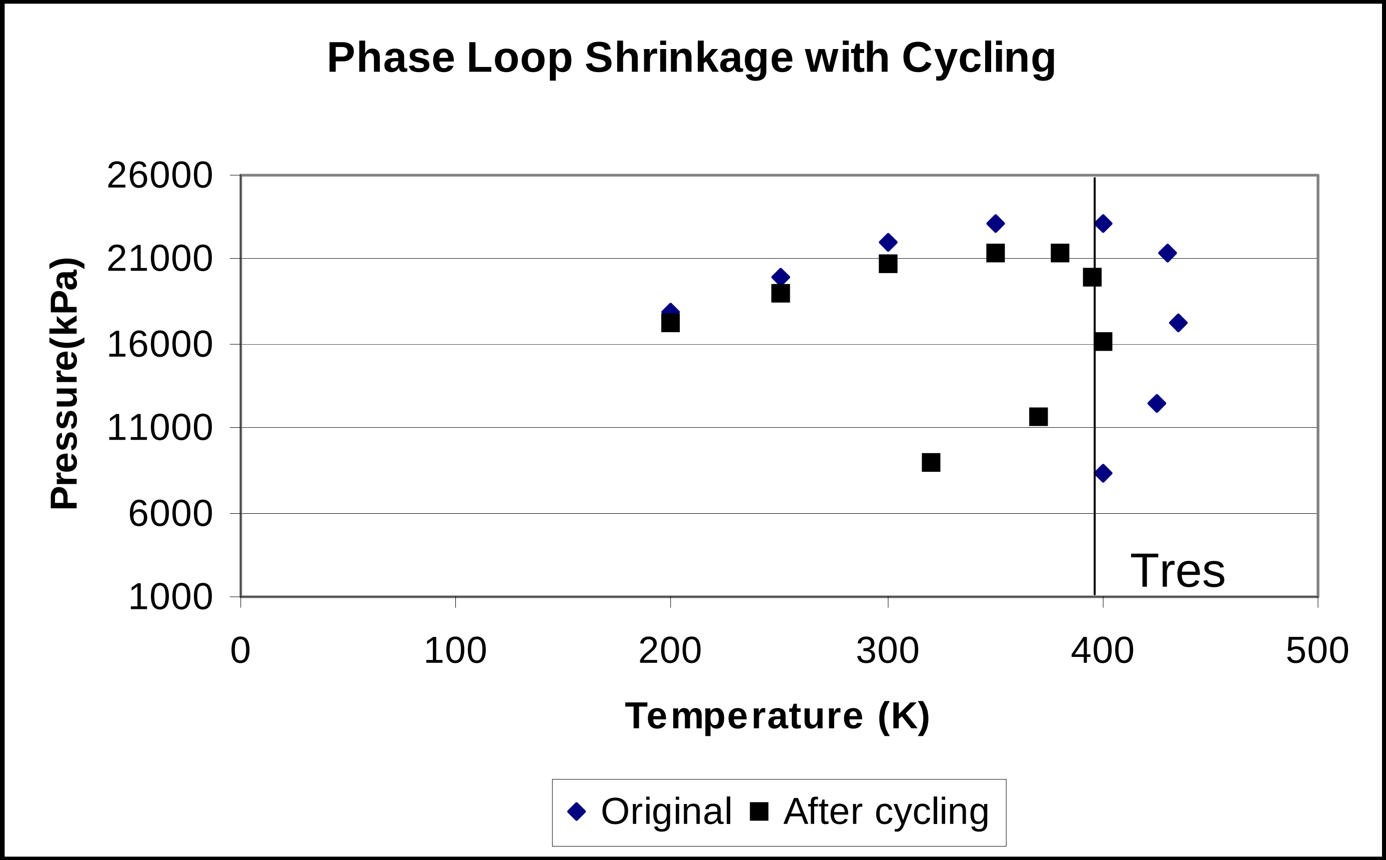
What are the options:

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

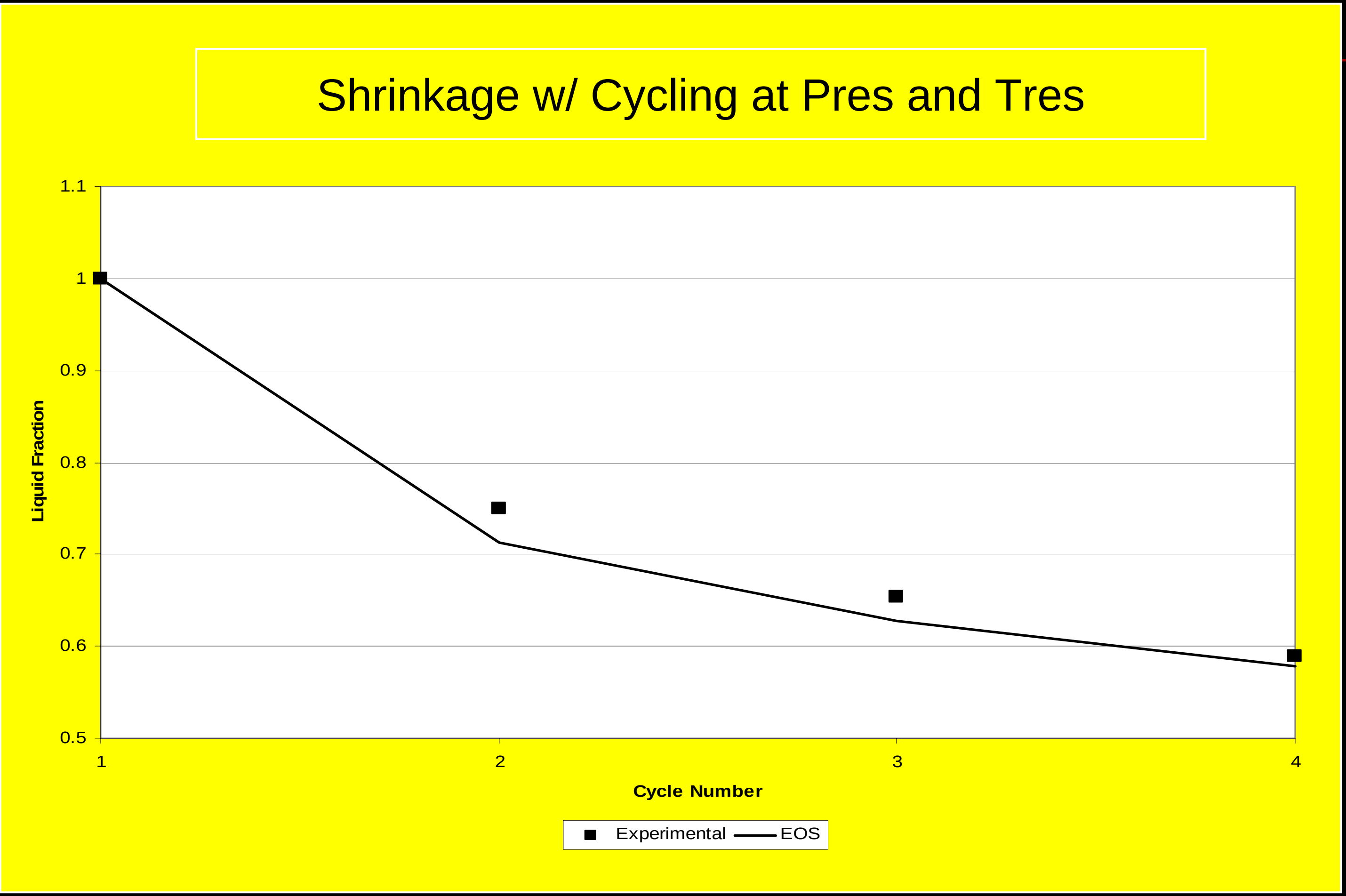
What is legal and what is moral?

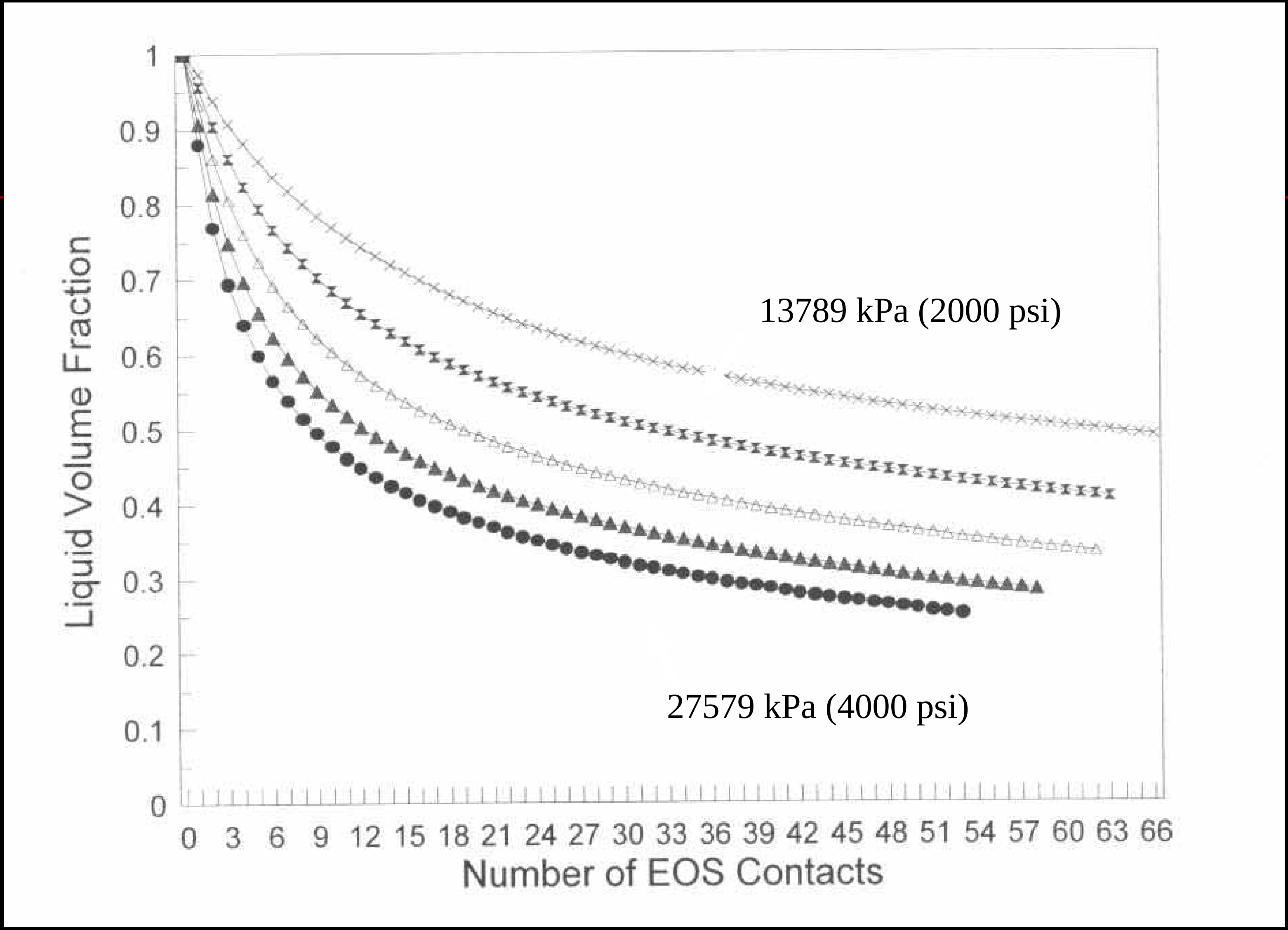
In north America – only if it affects gas production.

Easiest Pressure maintenance-start above dew point pressure



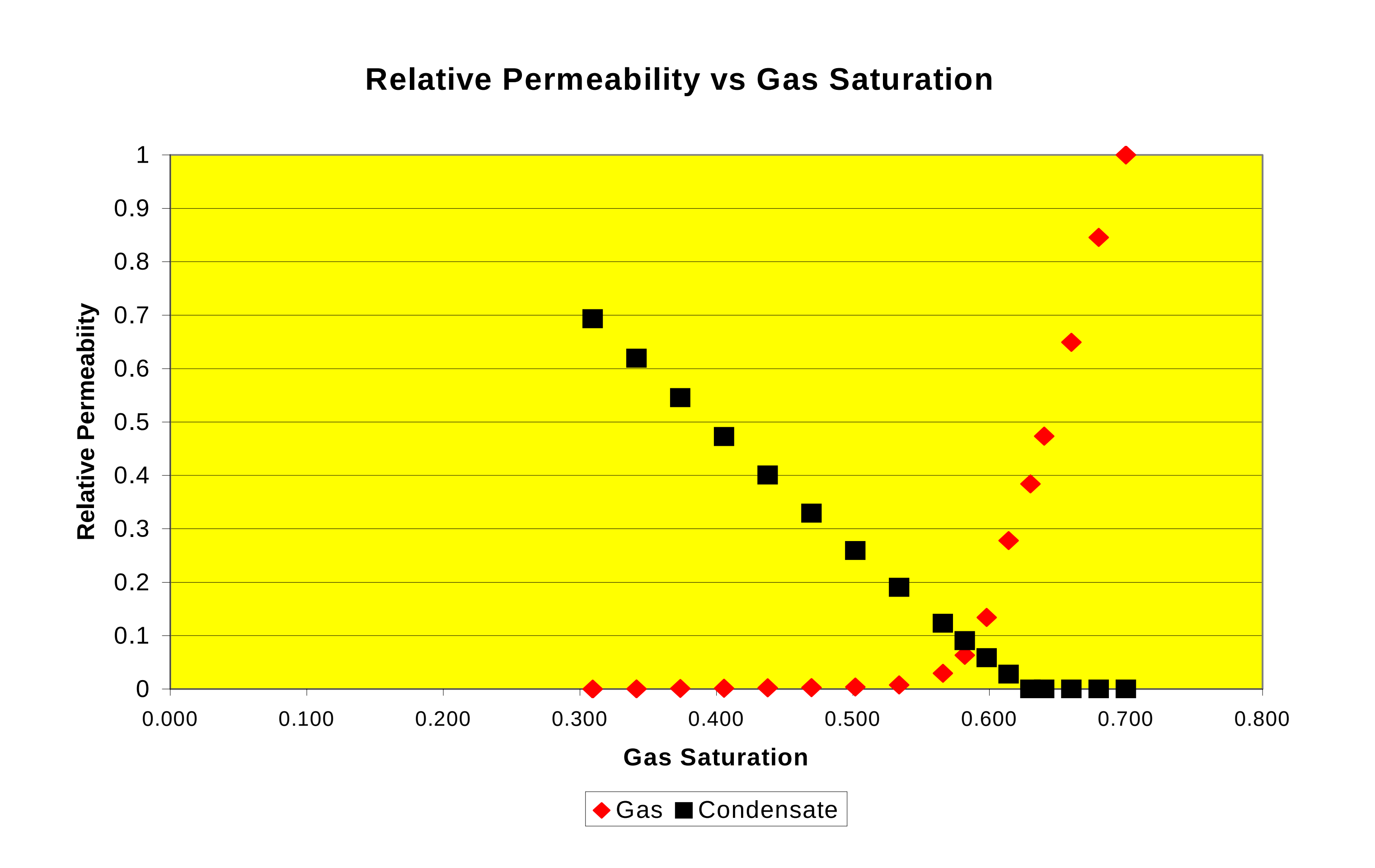
More common approach:





Liquid Volume Fraction
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 3 6 9 12 15 18 21 24 27 30 33 36 39 42 45 48 51 54 57 60 63 66
Number of EOS Contacts
13789 kPa (2000 psi)
27579 kPa (4000 psi)

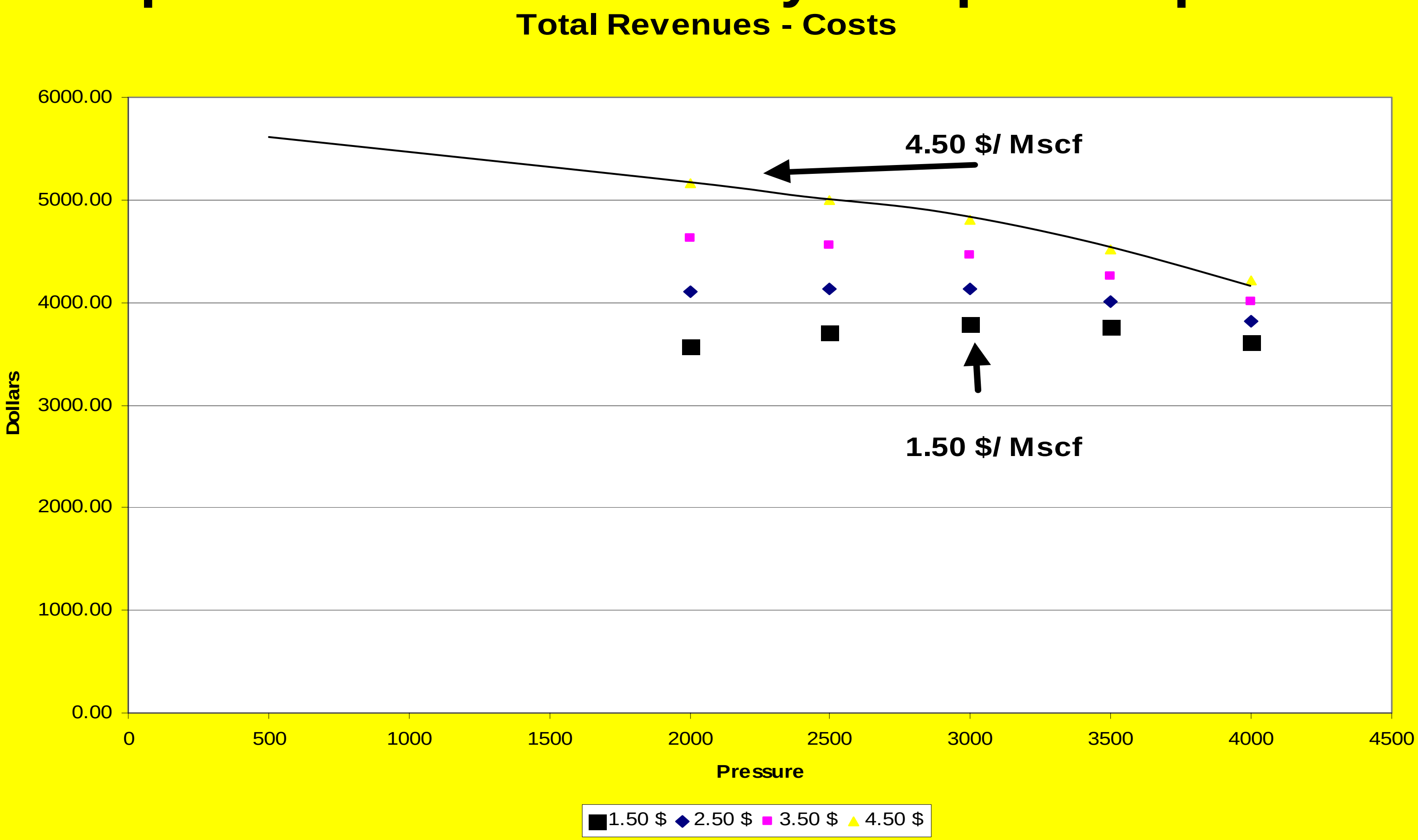
Another factor is productivity



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



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

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