Compositional Variation During Flow of Gas-Condensate Wells

Hai Xuan Vo and Roland N. Horne

Stanford University

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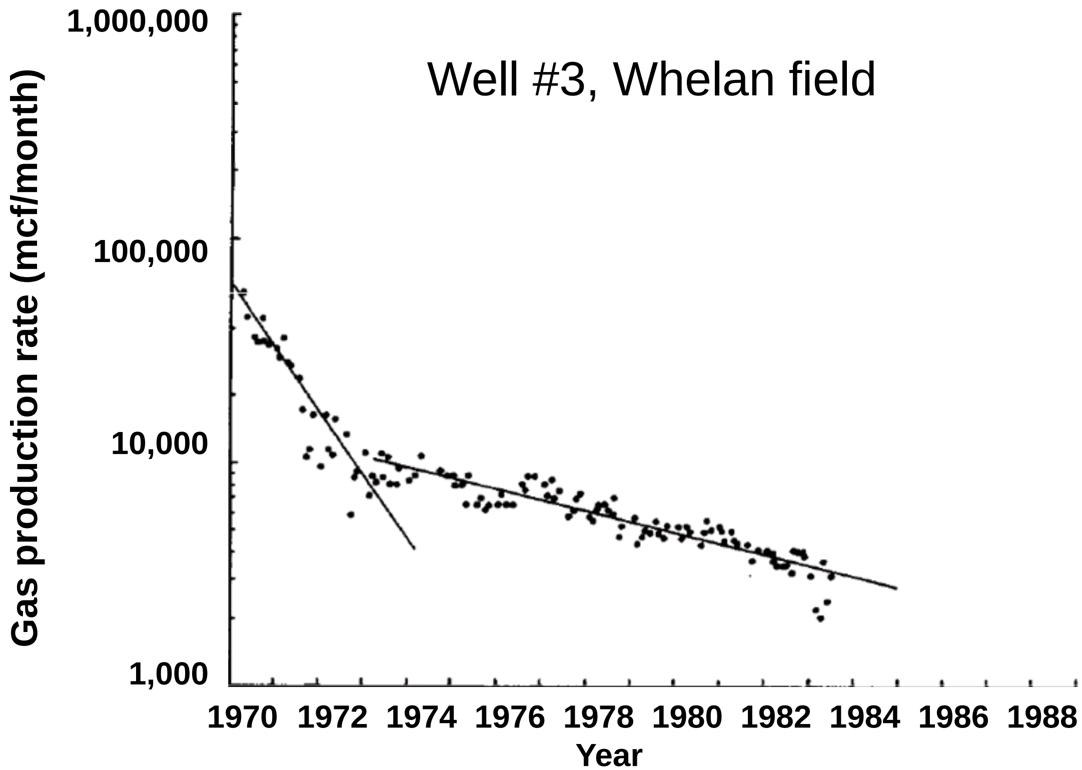
Condensate blockage

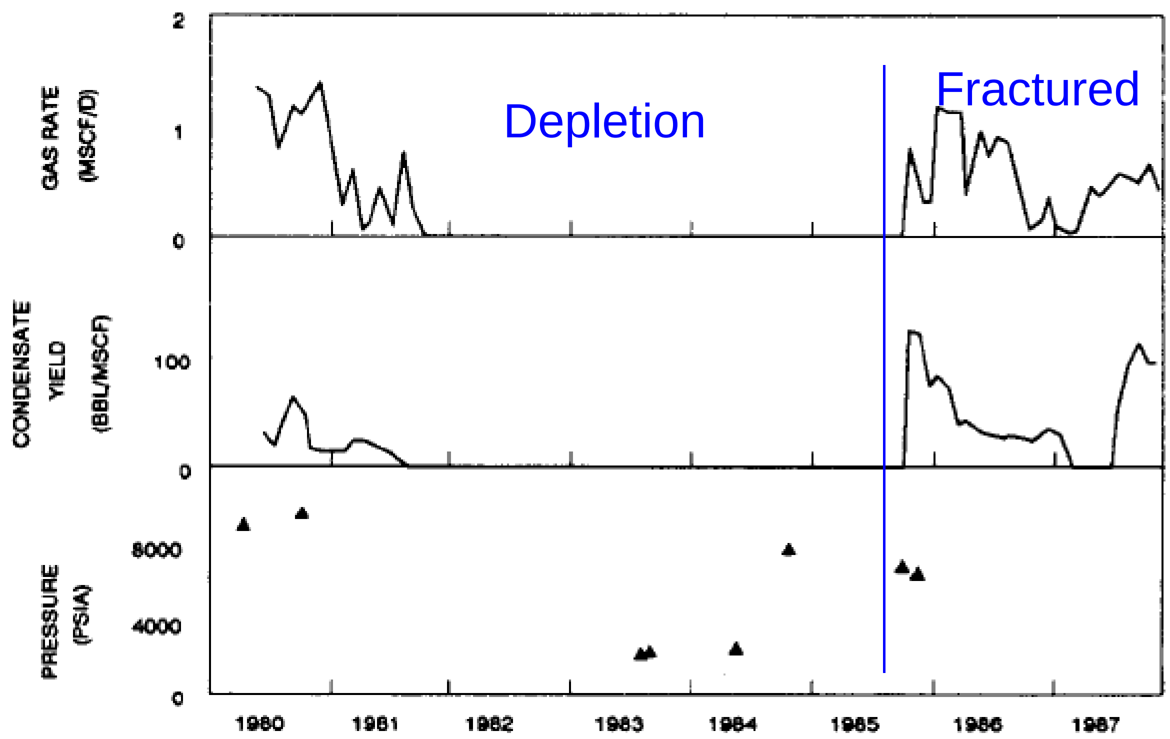


• The productivity loss caused by the condensate buildup is striking, in some cases, the decline can be as high as a factor of 30, according to Whitson (2005).

• Barnum et al. (1995) reviewed data from 17 fields, and concluded that severe loss of gas recovery occurs primarily in **low productivity reservoirs** with a permeability-thickness below 1000 md−ft.

Condensate Reservoir Performance

FIGURE 1 : EXAMPLE OF VERY POOR PERFORMANCE
IN A GAS CONDENSATE WELL



• One example of poor performance is shown (SPE 30767). When the flowing bottom-hole pressure reached the dew point, gas production declined rapidly and the well died. Pressure surveys indicated that the well was full of liquid hydrocarbons.

The composition change

- Heavy component composition in the flowing phase decreases once the reservoir pressure drops below the dew point pressure.

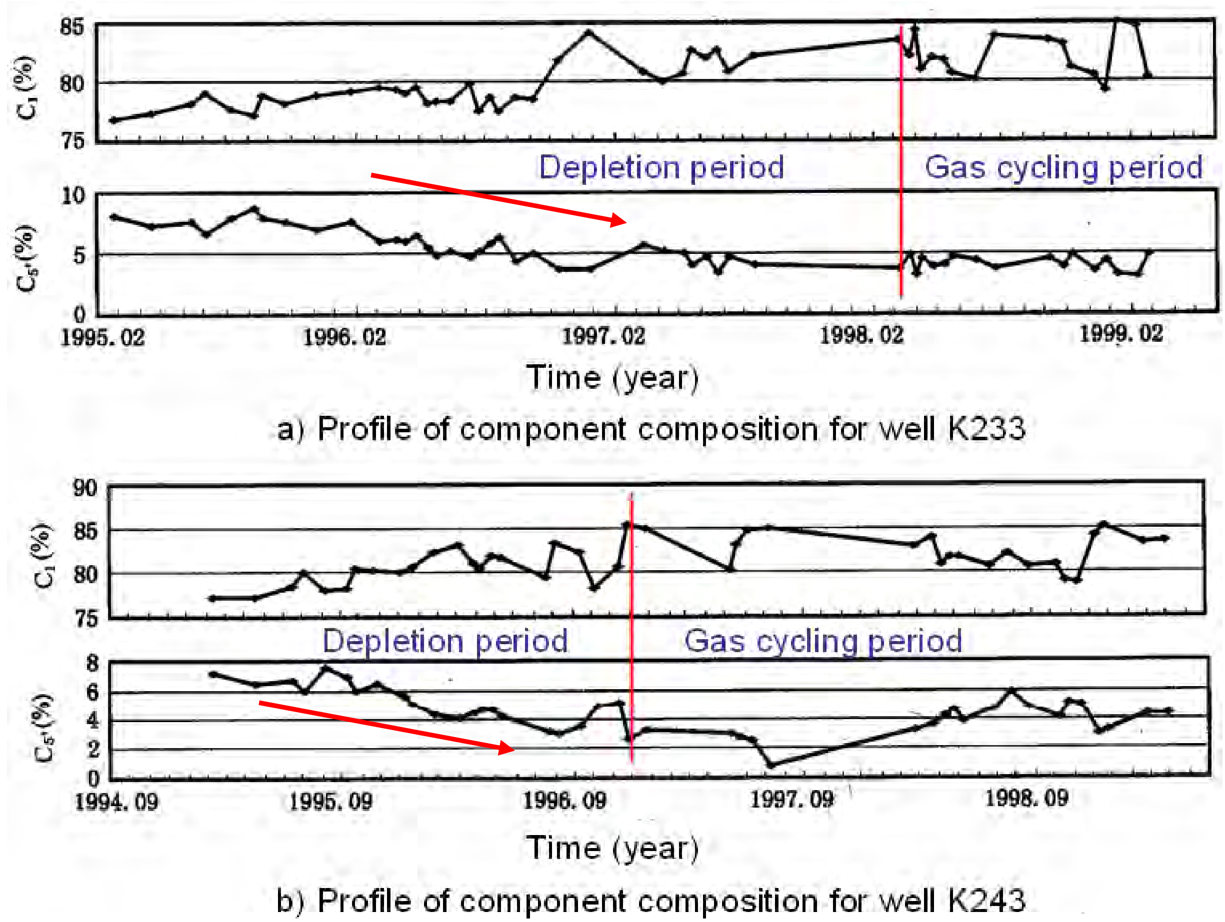
Composition	Well K401 @ initial reservoir condition	Well K233	
		Year 1995	Year 1999
C_1+N_2	77.28	83.86	86.08
C_2	7.935	7.78	9.3
C_3	3.126	2.38	2.6
C_4	2.505	1.52	0.65
C_5^+	8.908	4.4	1.31

(A field case from KekeYa gas field, China)

Source: Yuan Shiyi, Ye Jigen and Sun Zhidao "*Theory and practices in gas-condensate reservoir development*".

The composition change

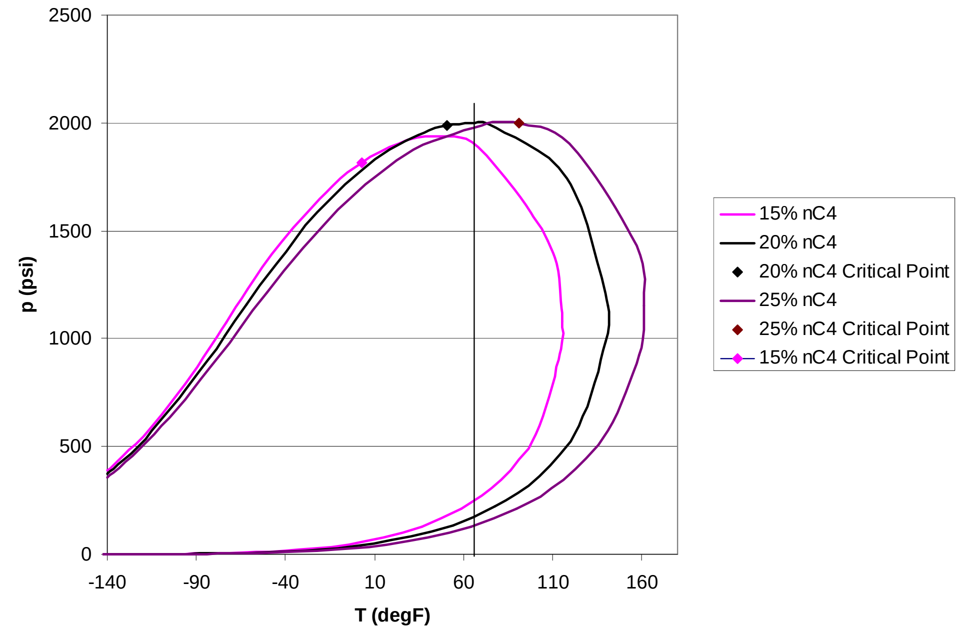
- The composition of the heavier component in the flowing phase decreases once the reservoir pressure drops below the dew-point pressure.

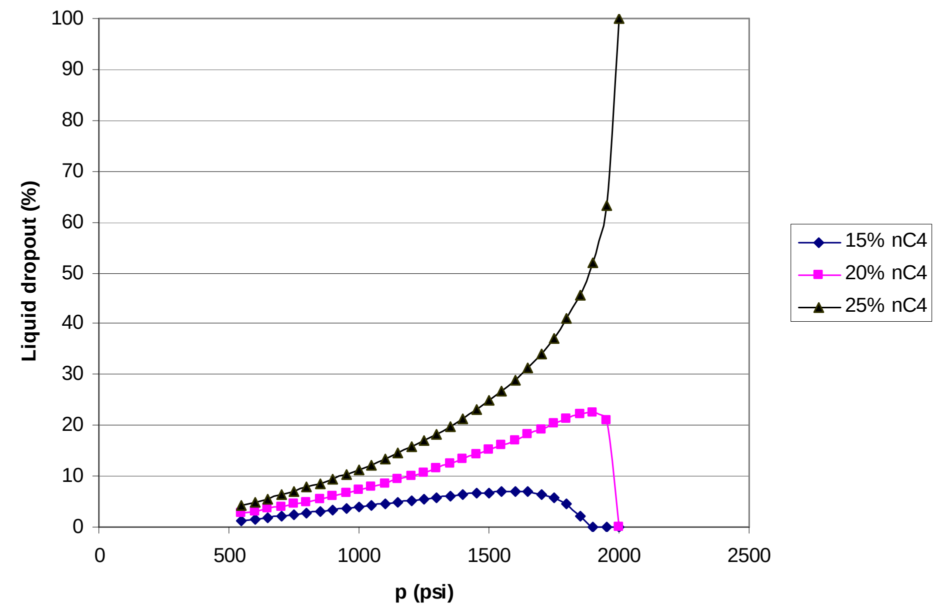


(A field case from KekeYa gas field, China)

Source: Yuan Shiyi, Ye Jigen and Sun Zhidao “*Theory and practices in gas-condensate reservoir development”.*

Compositional Variation (Simulation)





- Due to compositional variation during depletion, phase envelope will be shifted
- Compositional variation creates complexity in the understanding of the phase and flow behavior.

Why study composition?

- To understand the phase behavior change.
- To understand the dynamic condensate saturation build-up.

  Due to compositional variation and relative permeability constraints, the condensate saturation build-up is a dynamic process and varies as a function of time, place (distance to wellbore) and phase behavior.

- To develop optimum producing schemes.

  Changing the well producing schemes can affect the liquid dropout composition and can therefore change the degree of productivity loss.

Objectives of this study:

– Verify the composition change by experiment.

– Develop optimum producing schemes for condensate recovery.

Project Management Plan

- Task 1.0. Project Management Plan √
- Task 2.0. Technology Status Assessment √
- Task 3.0. Technology Transfer √
- Task 4.0. Scoping Study √
- Task 5.0. Condensate Banking Study – Numerical and Experimental √
- Task 6.0. Developing Optimal Production Strategy (in progress)

2010 Activities

Project Management Plan

- Task 1.0. Project Management Plan √
- Task 2.0. Technology Status Assessment √
- Task 3.0. Technology Transfer √
- Task 4.0. Scoping Study √
- Task 5.0. Condensate Banking Study – Numerical and Experimental (completed)
- Task 6.0. Developing Optimal Production Strategy (third stage)

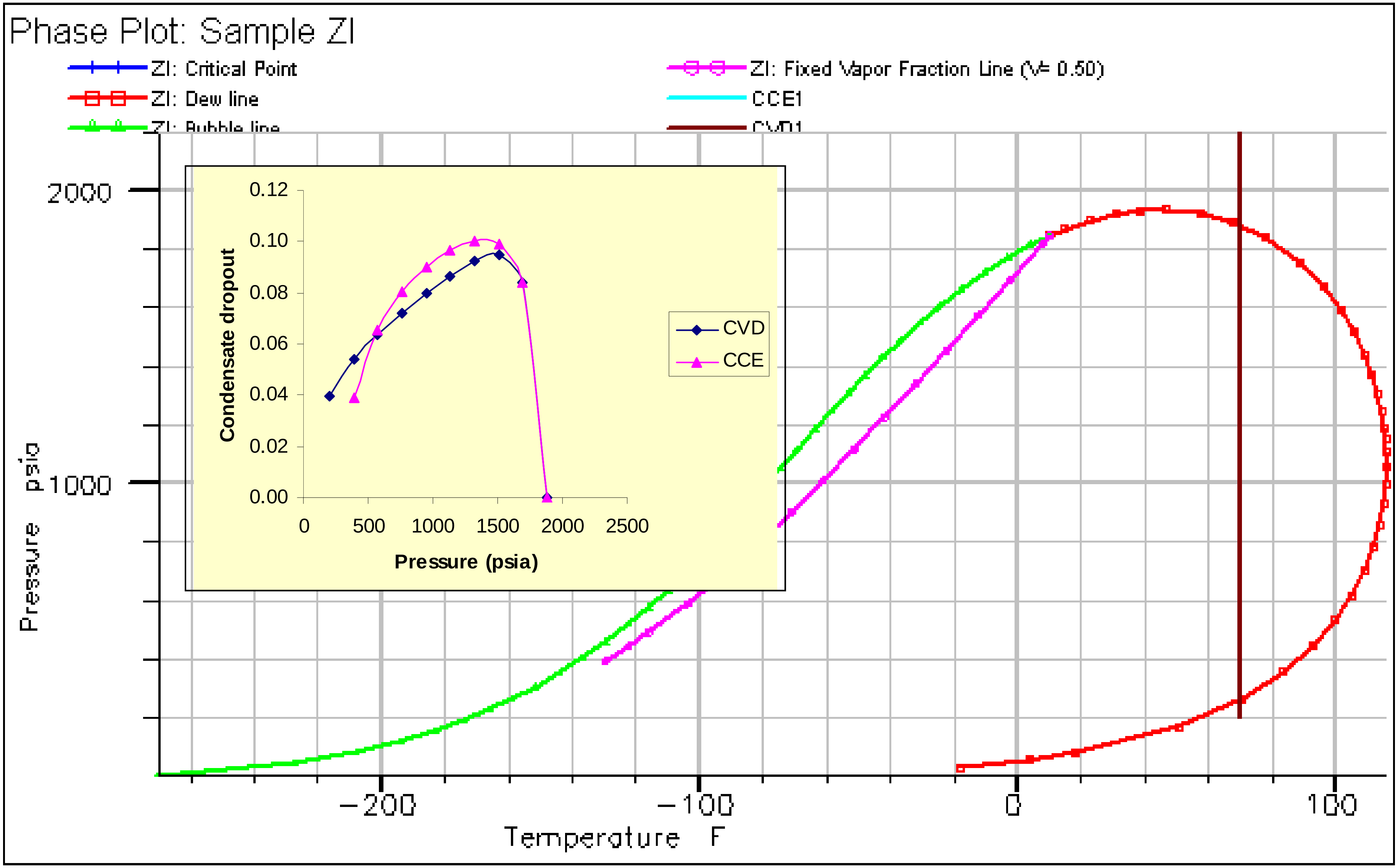
Outline

- Research motivation. √
- Two-phase study.
- Three-phase study (including water).
- Production optimization using BHP strategy.

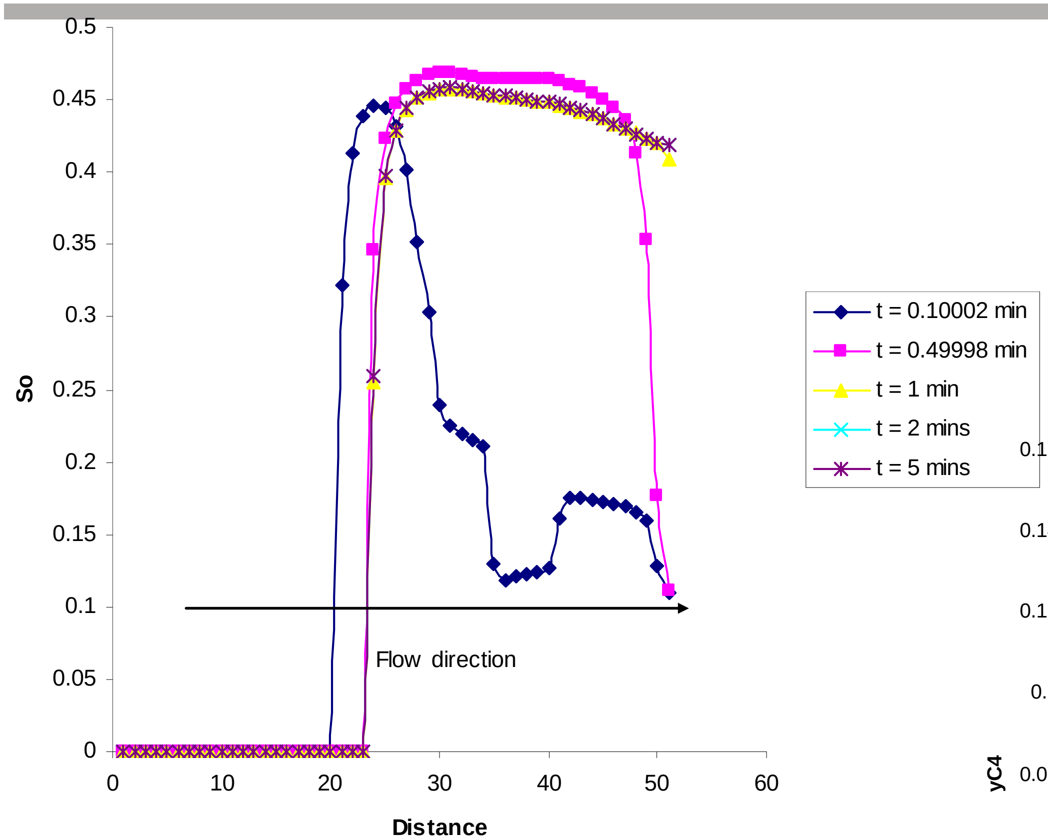
Experiment Design (1)

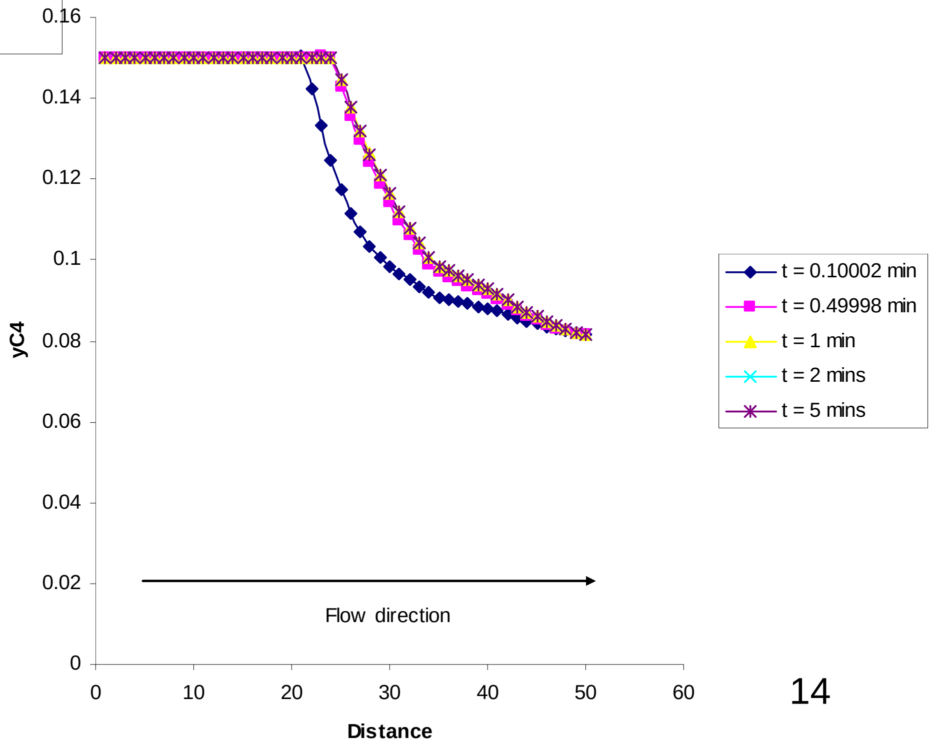
- Synthesis gas condensate mixture of C_1-nC_4 = 0.85/0.15 mole fraction.
- Performed at room temperature (70°F).
- Berea sandstone core (porosity = 16%, k = 9.3 md).

Experiment Design (2)



Two-Phase Simulation for Core Flooding Experiment

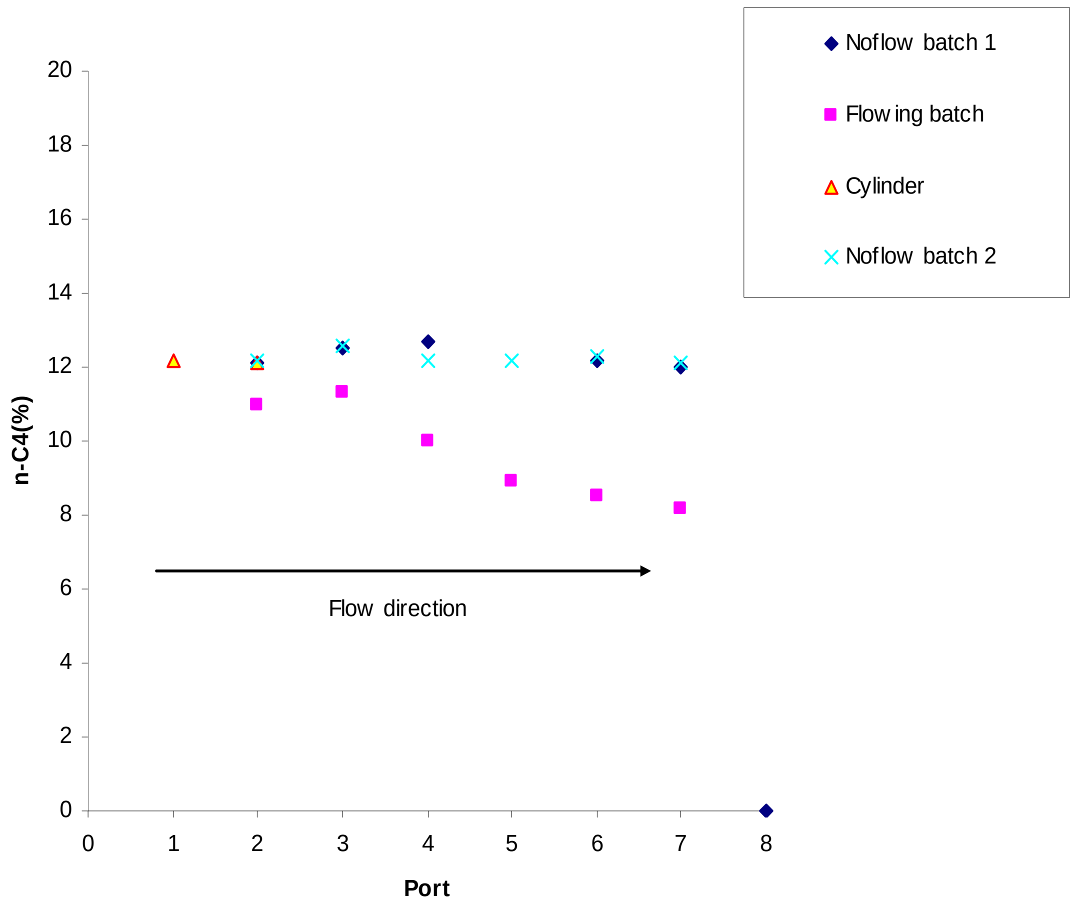




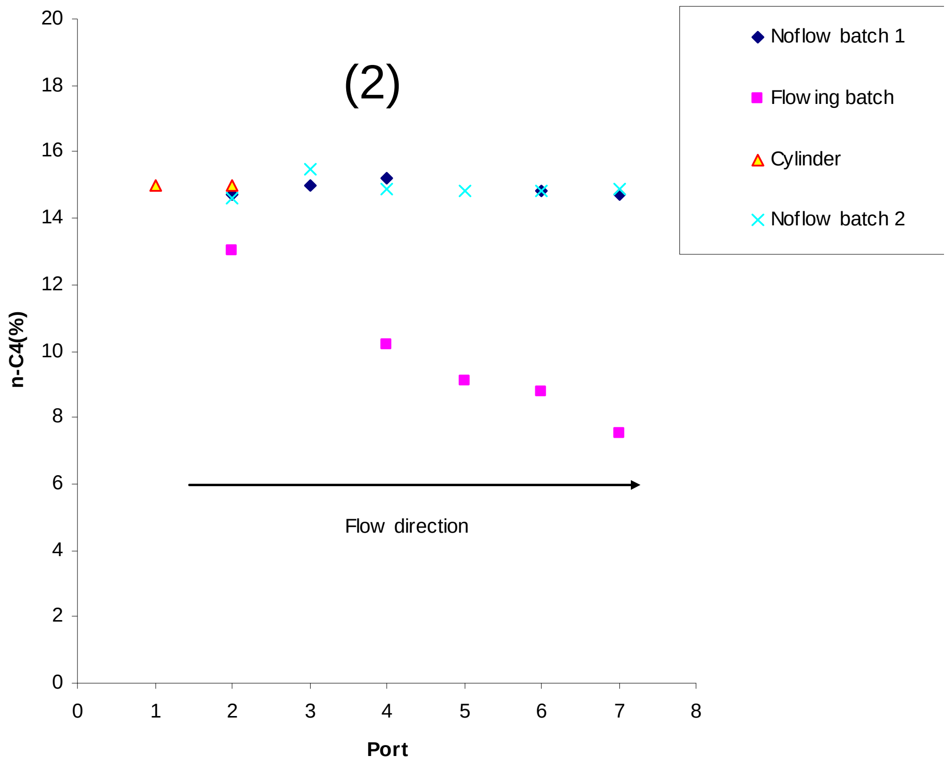
Two-Phase System: Noncapture Experiment (1)

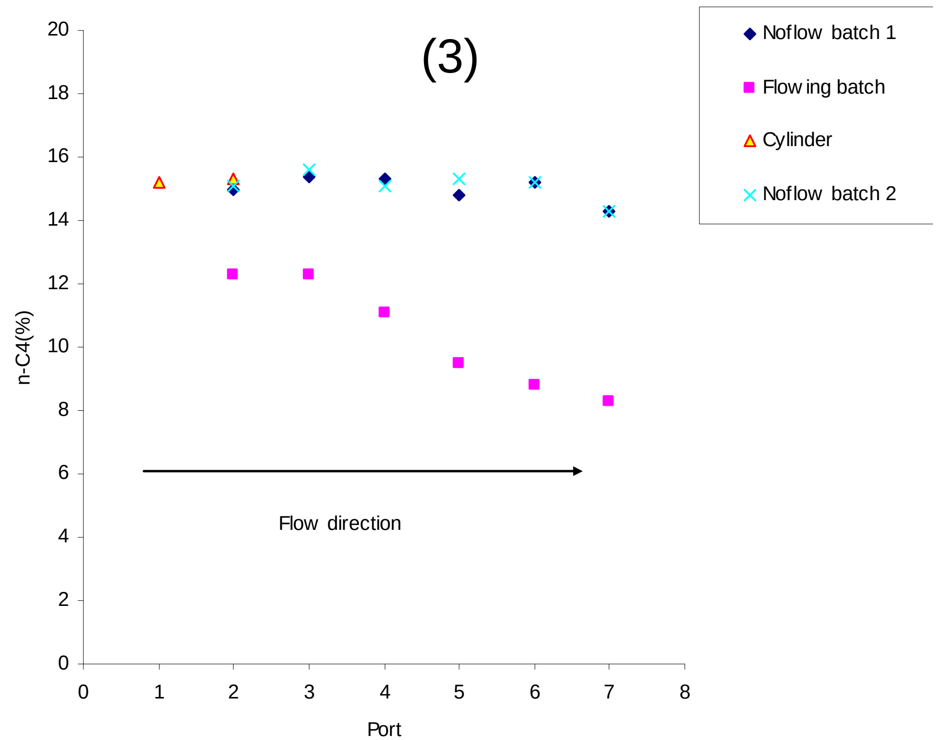
Steps:

- Core is vacuumed and pre-saturated with C_1 at 2200 psi (about 300 psi above dew-point pressure of C_1-nC_4).
- Flush the C_1-nC_4 mixture throug the core at 100 psi differential pressure for 10 minutes.
- Close downstream valve and take samples in no-flow condition.
- Flush the C_1-nC_4 mixture throug the core at 1000 psi differential pressure for 3 minutes and take samples in flowing condition.



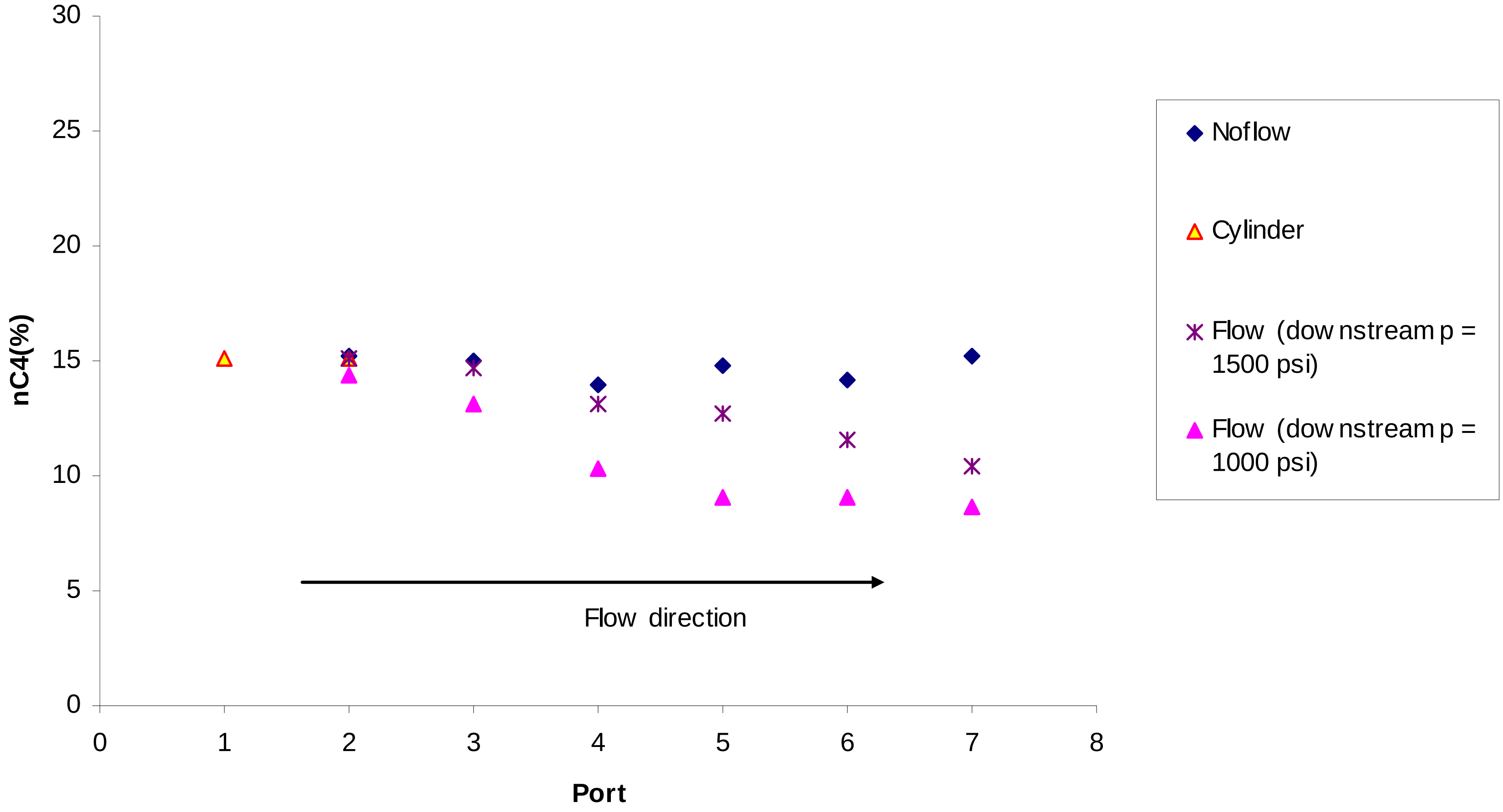
Two-Phase System: Noncapture Experiment (2)





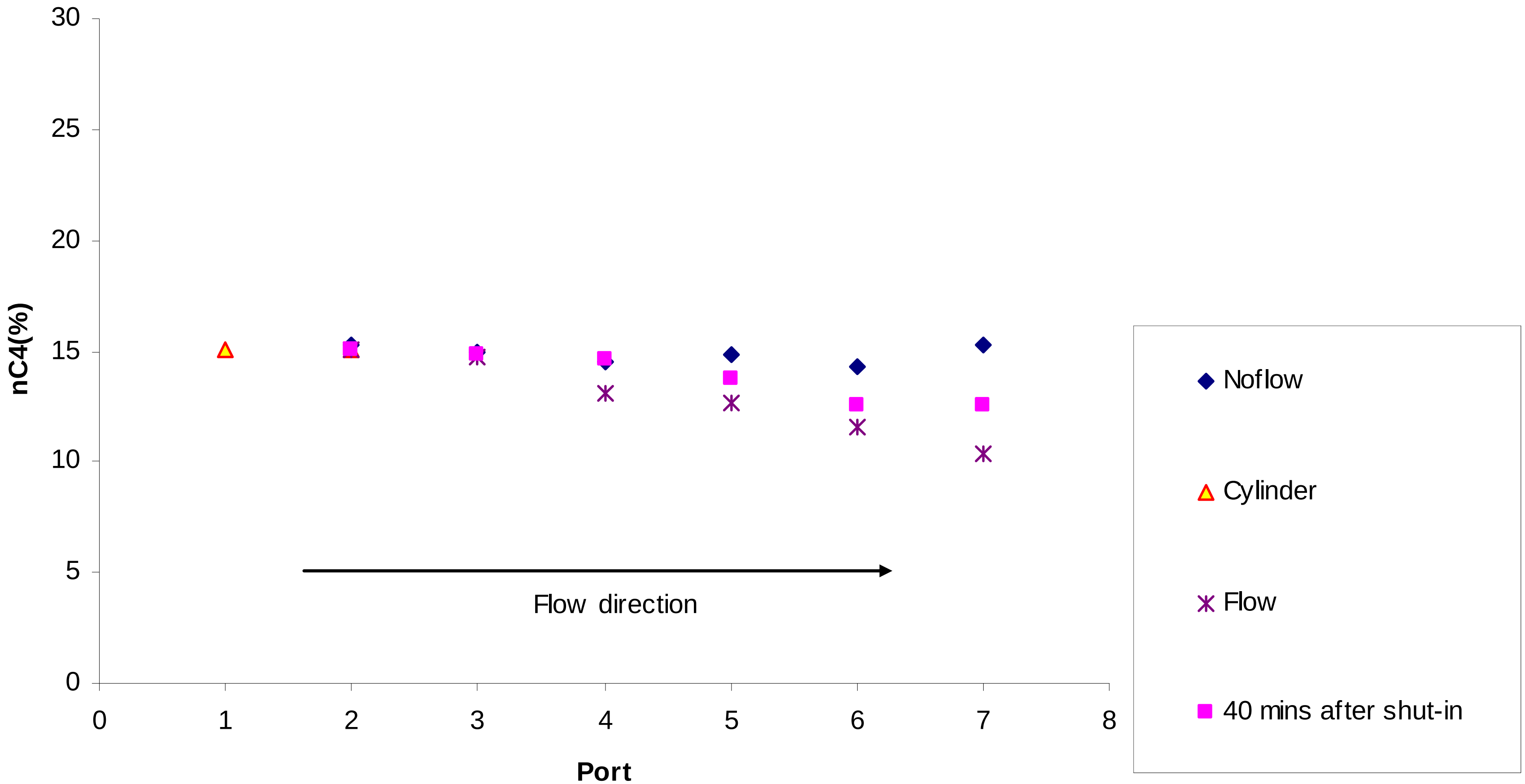
- Did two more experiments following the same procedure.
- Good repeatability.

Two-Phase System: Noncapture Experiment (3)
Effect of different BHP on composition



- **The lower *BHP*, the less heavy component measured in the flowing phase.**

Two-Phase System: Noncapture Experiment (4) - Effect of shutting in well



- **Shutting in the well does not revaporize the condensate completely. The fluid has changed from a gas-condensate to a volatile oil.**

Two-Phase System: Capture Experiment (1)

Steps:

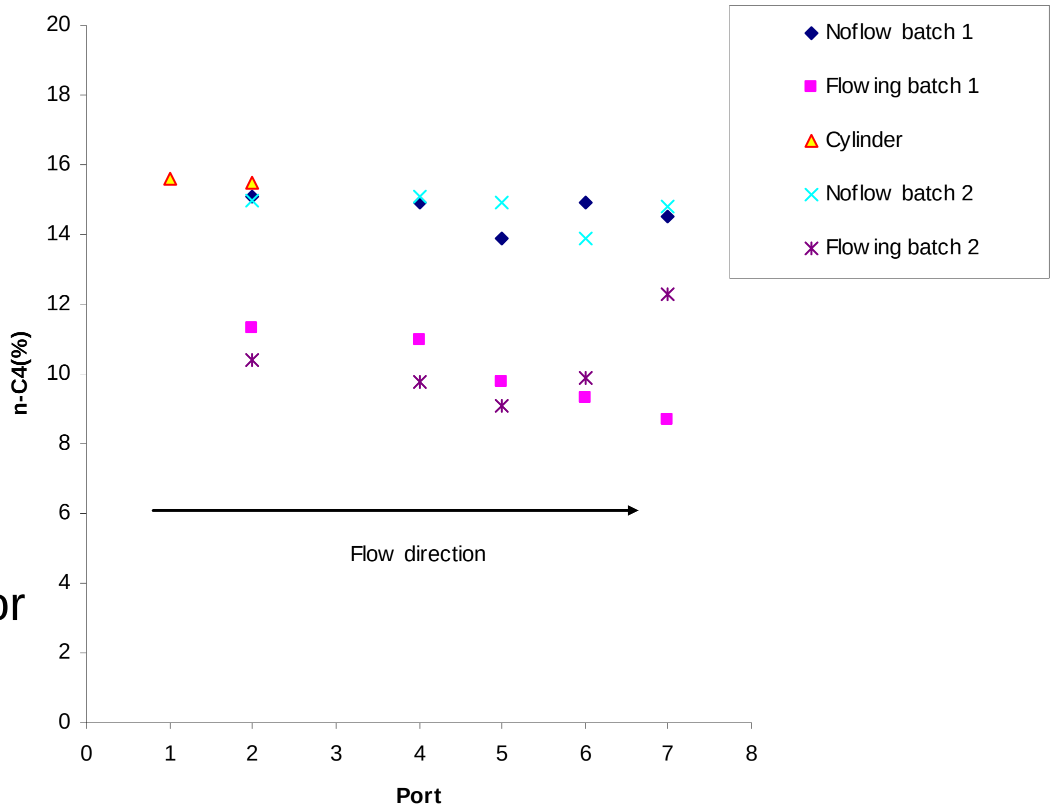
• Core is vacuumed and presaturated with C_1 at 2200 psi (about 300 psi above dew point pressure of C_1-nC_4).

• Flush the C_1-nC_4 mixture through the core at 100 psi differential pressure for 10 minutes.

• Close downstream valve and take samples in no-flow condition.

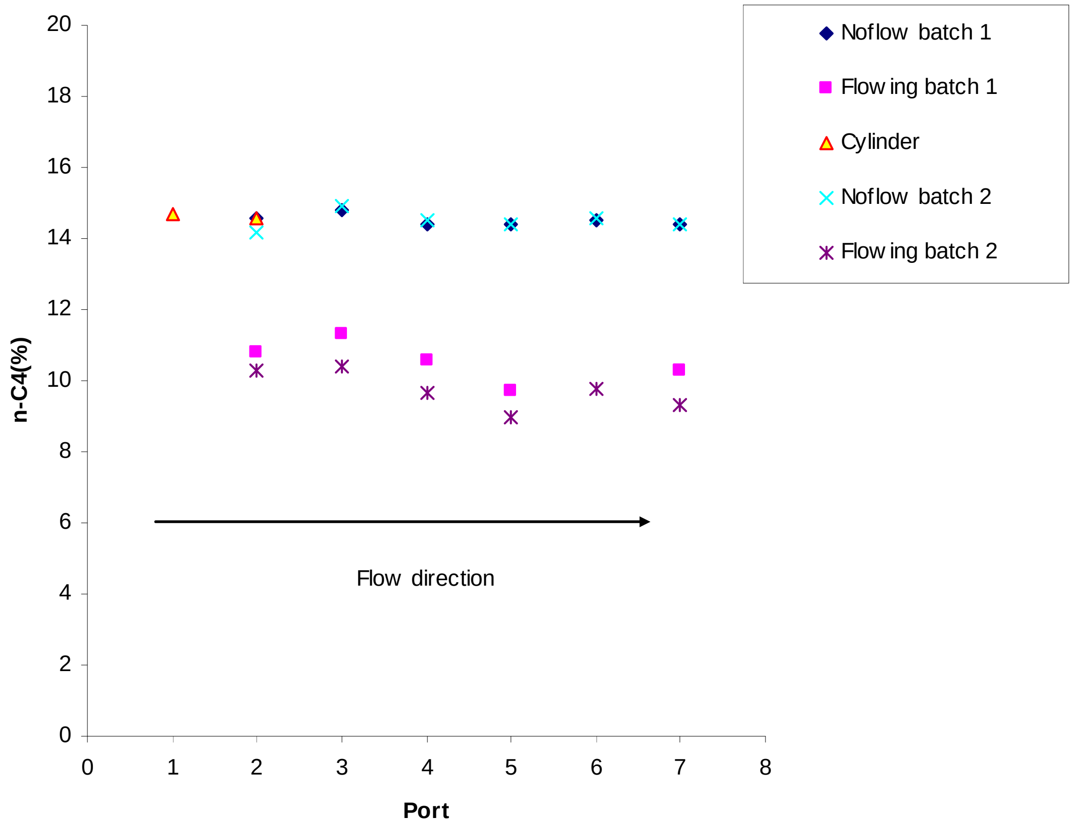
• Flush the C_1-nC_4 mixture through the core at 1000 psi differential pressure for 3 minutes.

• Close upstream and downstream valves and take samples in capture-mode.



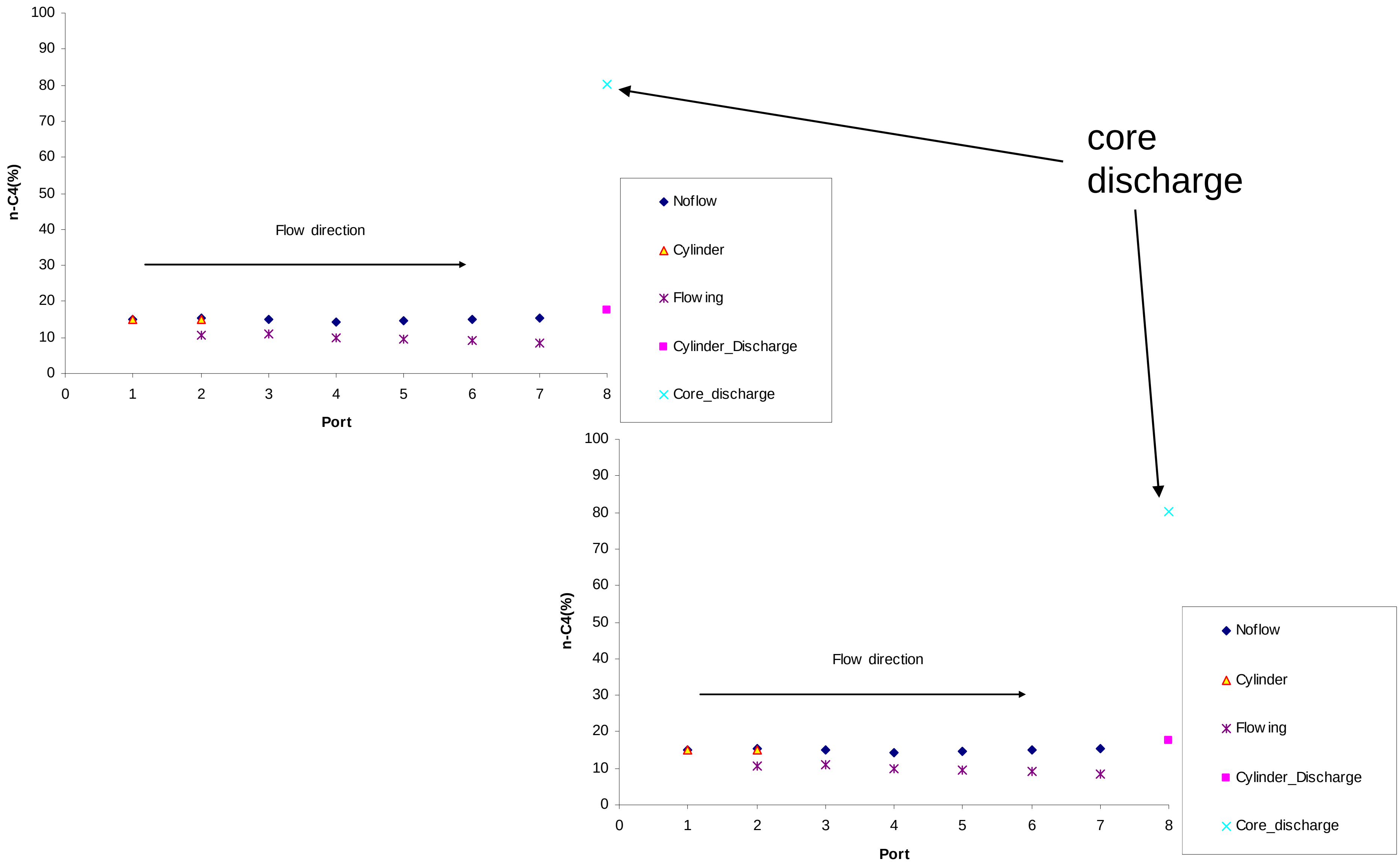
• Good repeatability in static condition and flow condition

Two-Phase System: Capture Experiment (2)



- Did three more experiments following the same procedure.
- Pore volume is small so the measurements are affected but good repeatability in general.

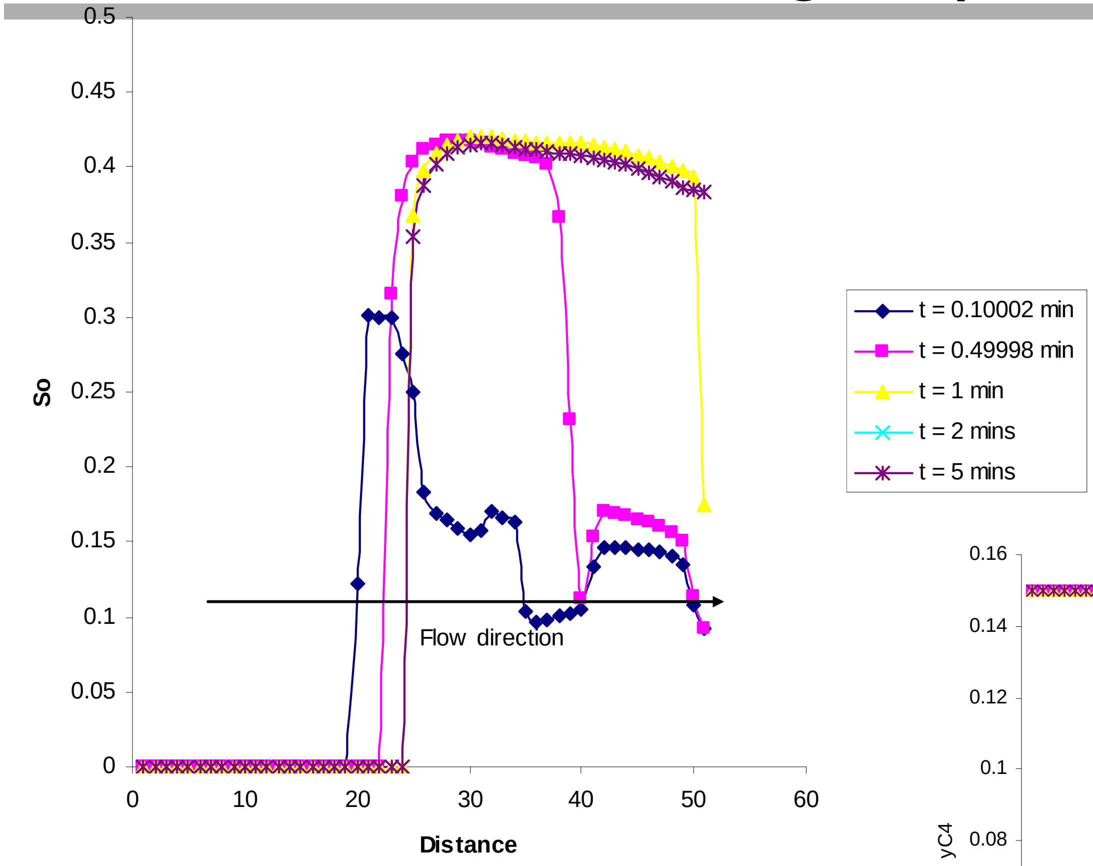
Two-Phase System: Capture Experiment (3)

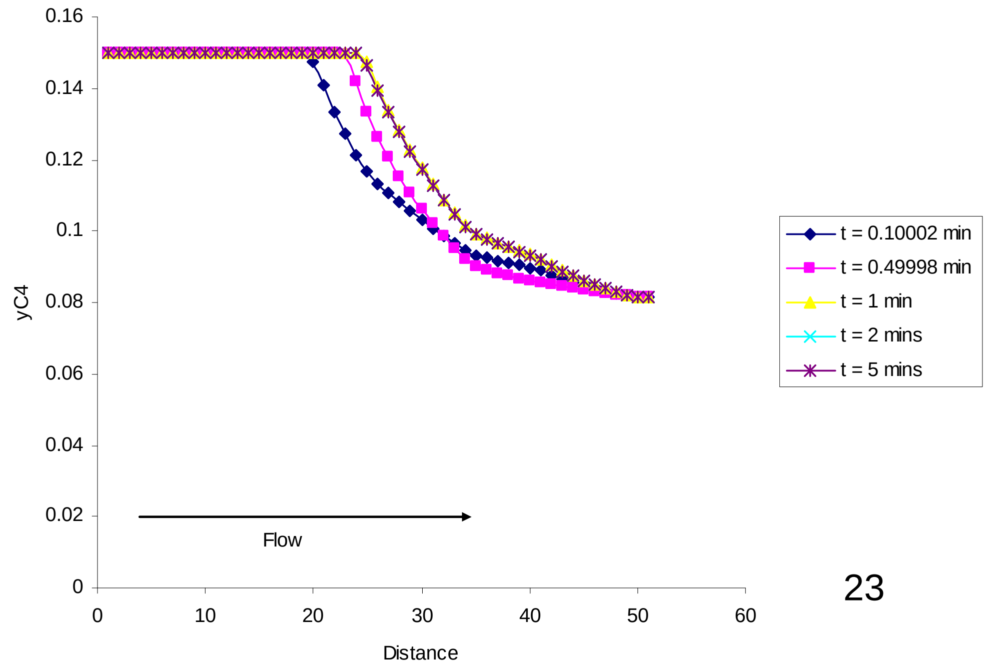


Three-Phase Simulation for Core Flooding Experiment (1)

- Extension of previous work (two-phase gas-oil) but now with presence of immobile water (three-phase gas-oil-water).
- Mixture of C_1-nC_4 with initial molar composition = 0.85/.015.
- S_{or} = 0.24.
- S_{gr} = 0.
- S_{wi} = 0.16.

Three-Phase Simulation for Core Flooding Experiment (2)

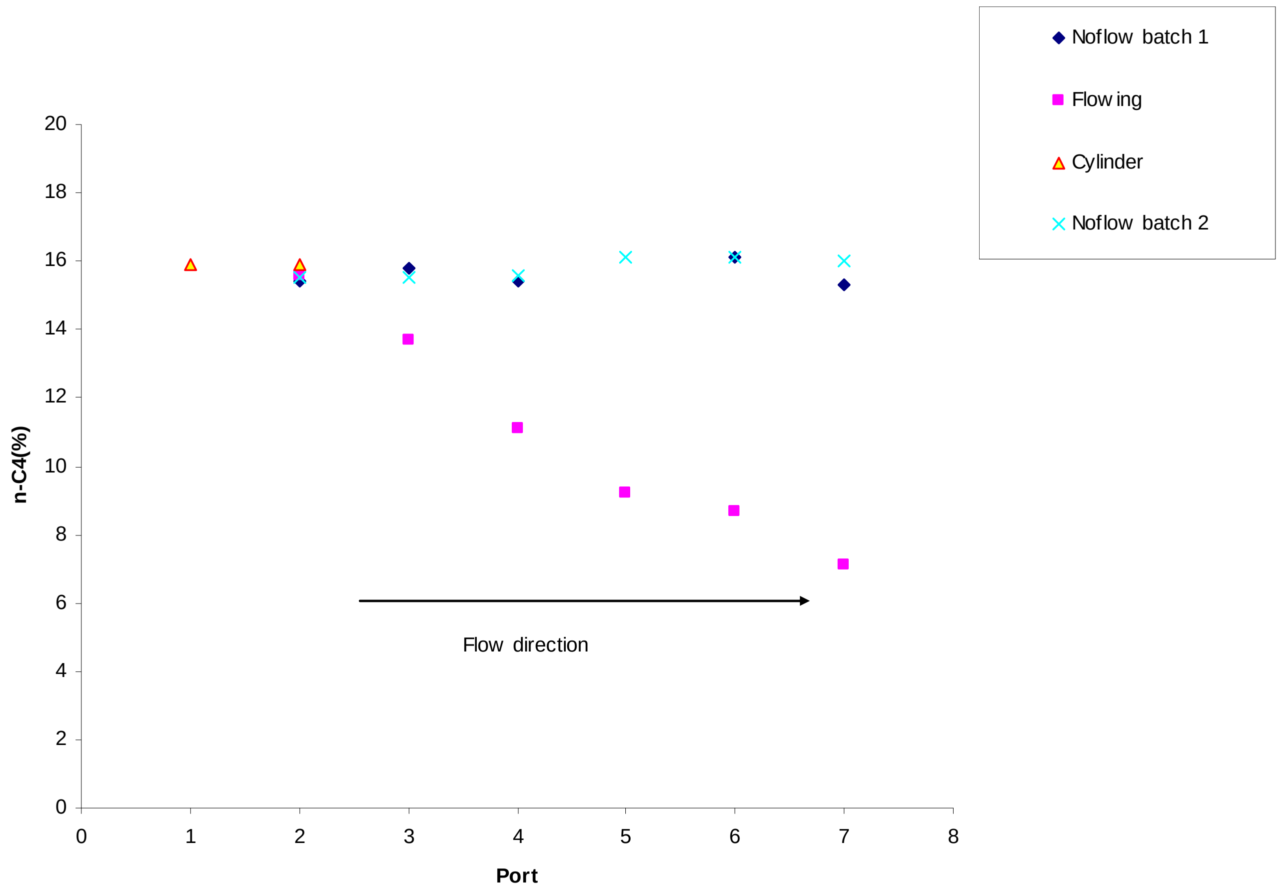




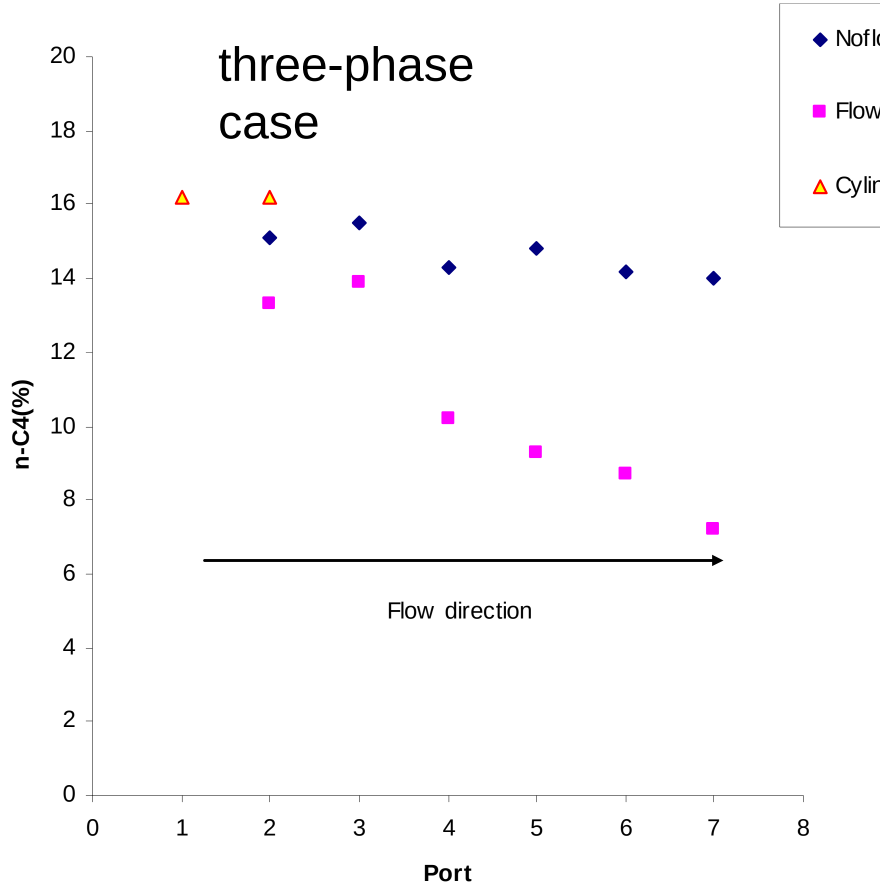
Three-Phase System: Noncapture Experiment (1)

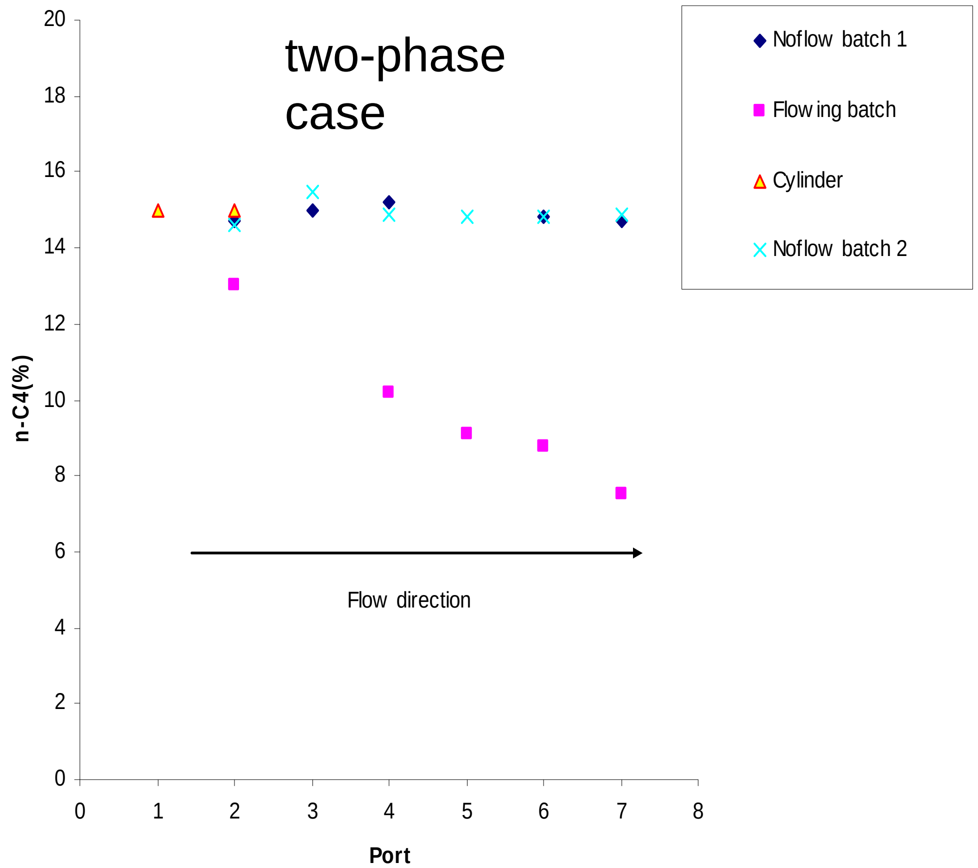
Steps:

- Core is vacuumed and saturated with water.
- Water is drained to immobile water saturation by flushing C_1 at 50 psi and lifting the upstream side of the core to 30 degree angle.
- Presaturated with C_1 at 2200 psi (about 300 psi above dew point pressure of C_1-nC_4).
- Next steps are the same as the cases without the immobile water.



Three-Phase System: Noncapture Experiment (2)



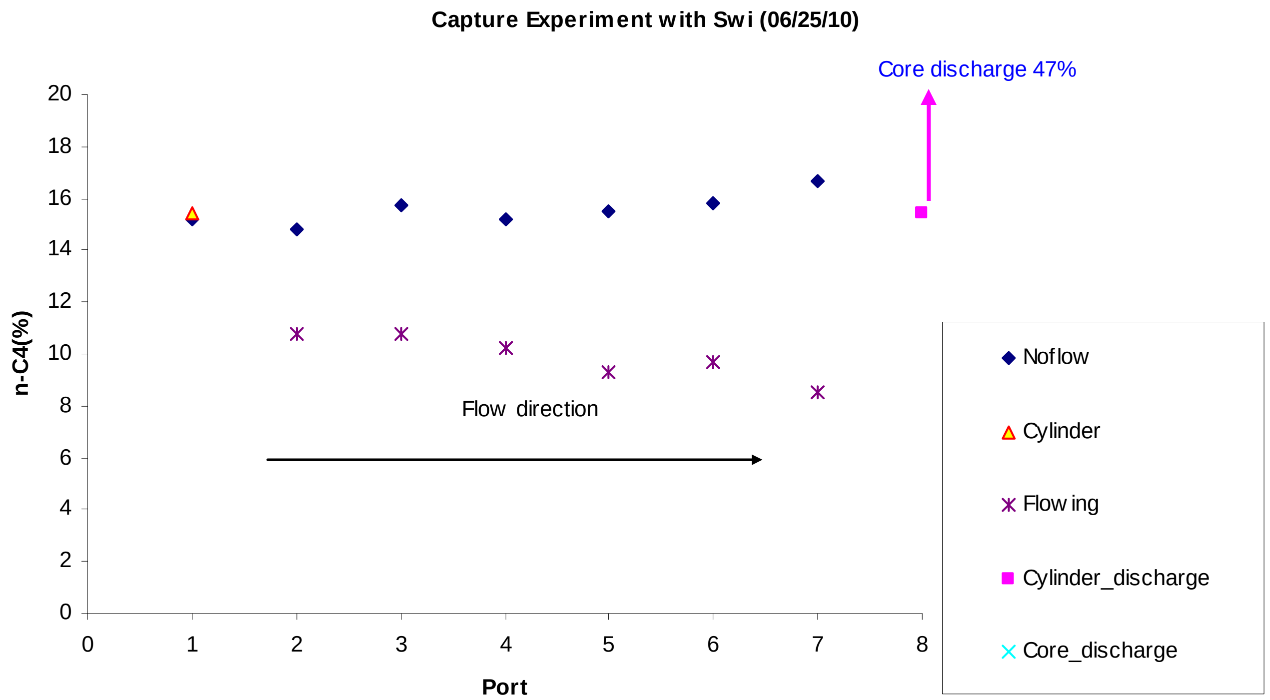


- Did another experiment.
- Result shows same trend of compositional variation to the two-phase case.

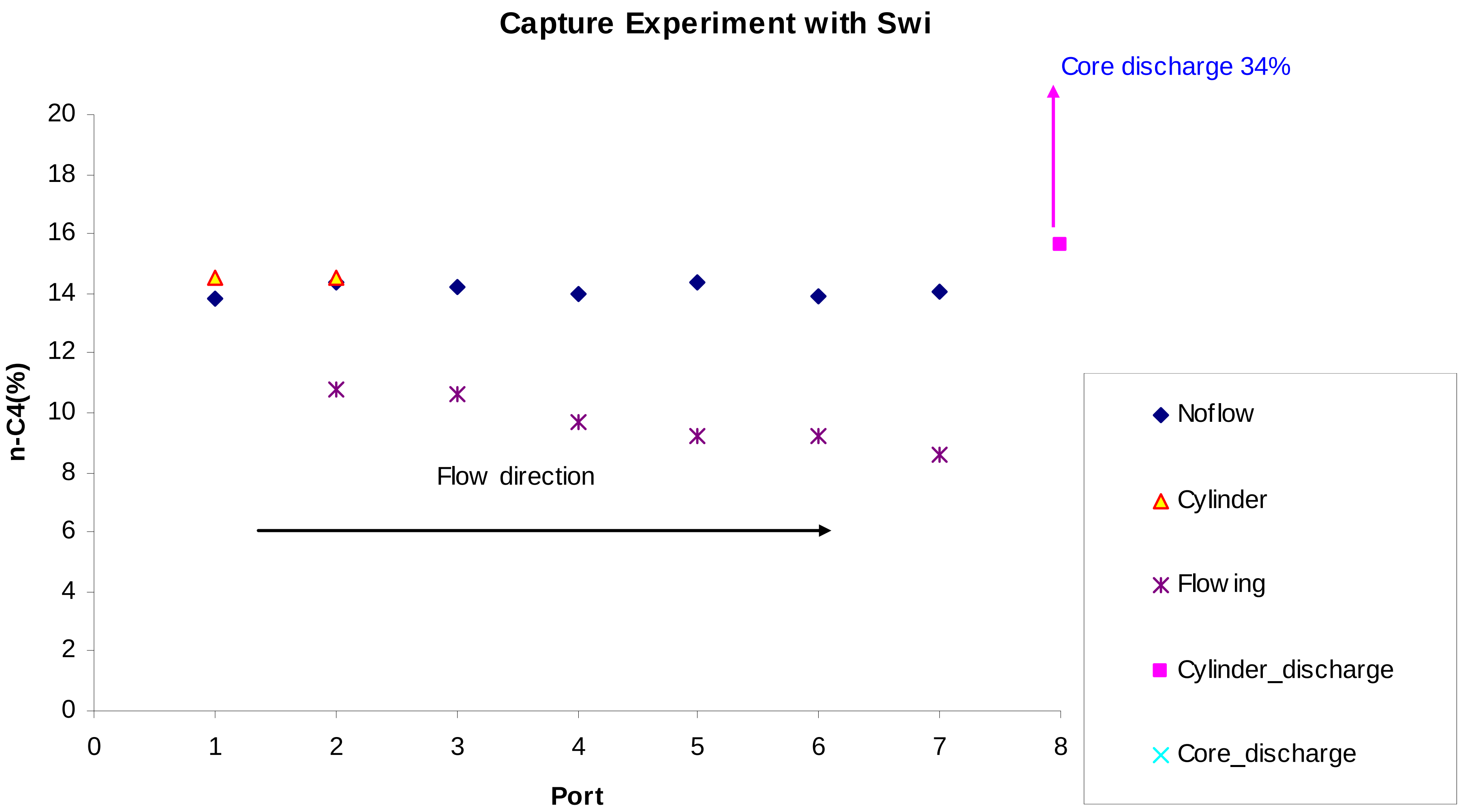
Three-Phase Case, with immobile water - capture experiment (1)

Steps:

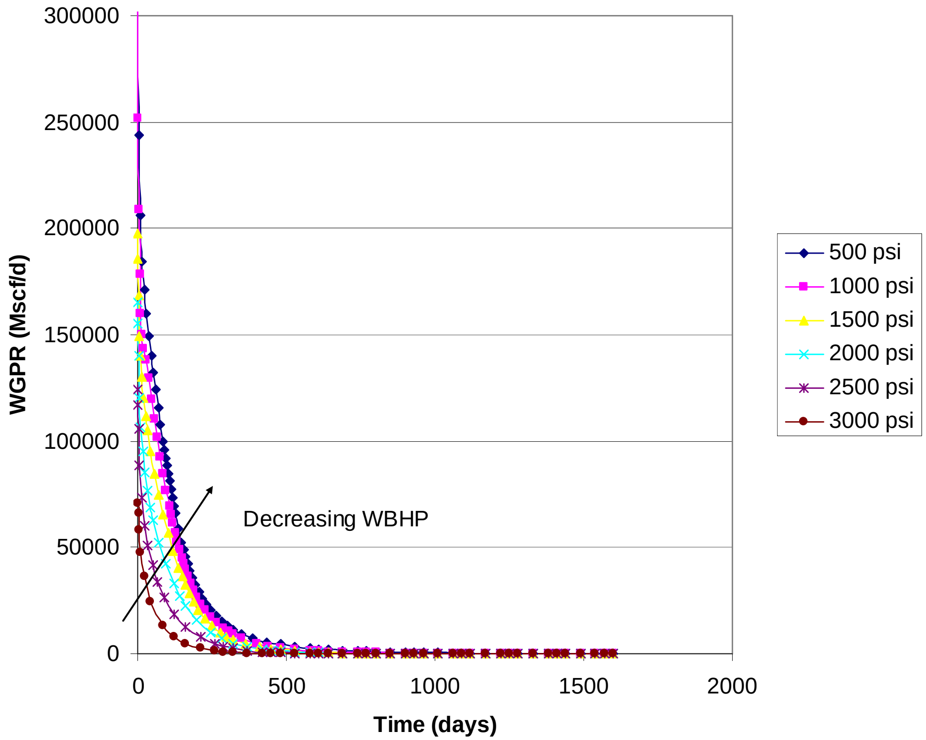
- Core is vacuumed and saturated with water.
- Water is drained to immobile water saturation by flushing C_1 at 50 psi and lifting the upstream side of the core to 30 degree angle.
- Presaturated with C_1 at 2200 psi (about 300 psi above dew point pressure of C_1-nC_4).
- Next steps are the same as the cases without the immobile water.

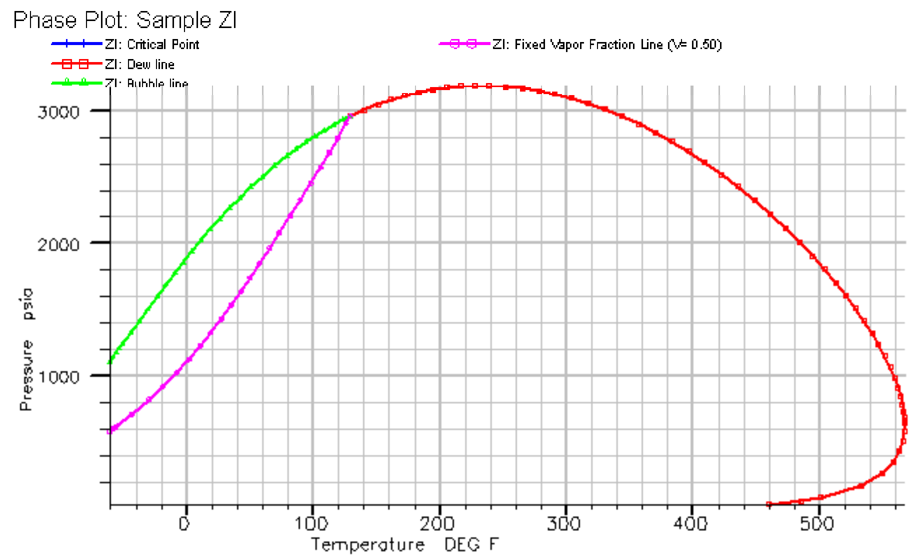


Three-Phase Case, with immobile water - capture experiment (2)

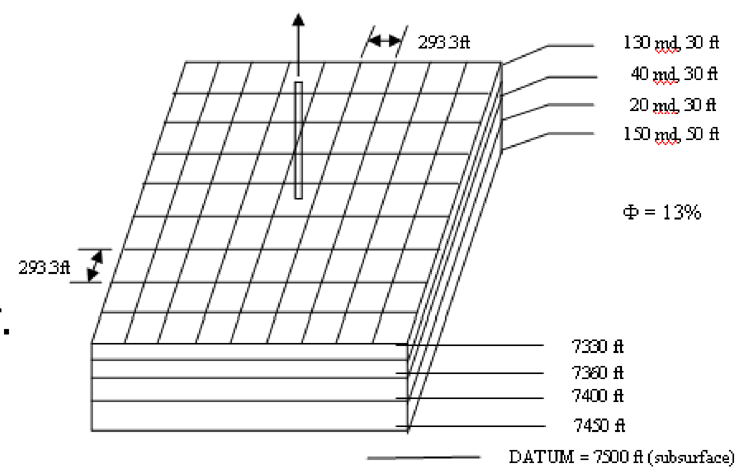


Gas Productivity vs. BHP Schemes





- Reservoir with 9×9×4 blocks, 4 layers.
- Only one production well.
- Nine-component system, immobile water.
- Reservoir temperature 200°F.
- Initial reservoir pressure 3550 psi.



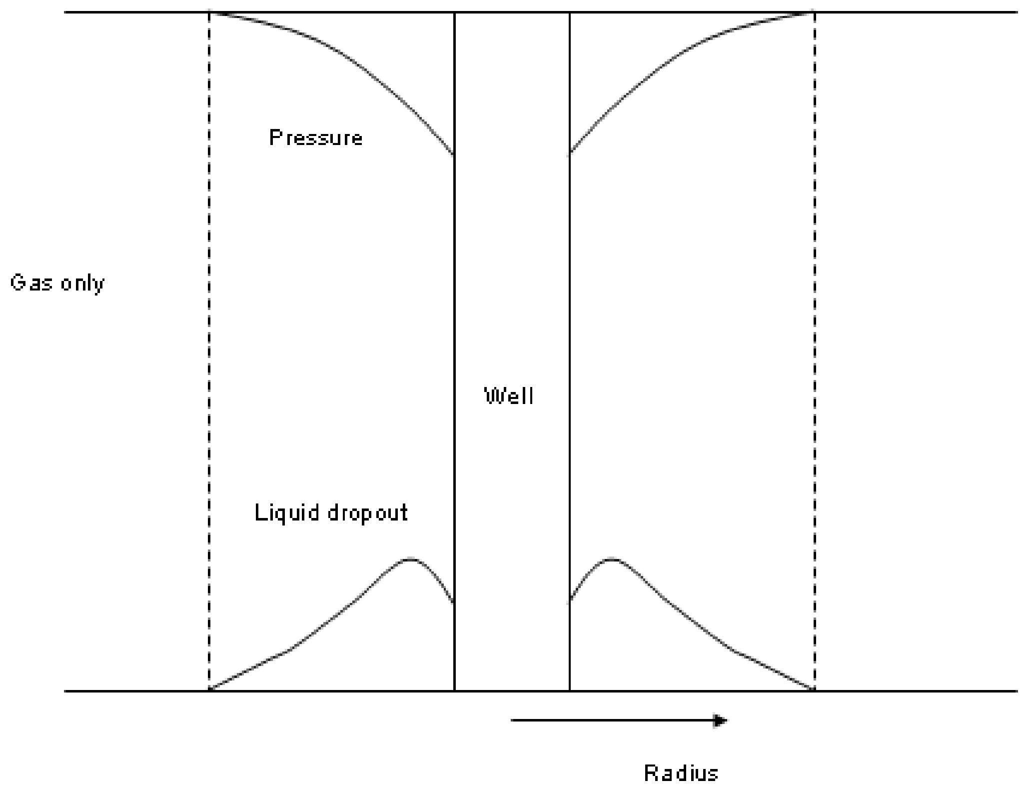
Conclusions

- Repeatability of the experiments was achieved, demonstrating the validity of the results. (Phase 1)
- Due to the change of local composition, the phase envelope of the mixture will shift. (Phase 1)
- Shutting a well to remove the condensate banking is not a good strategy as the condensate will not be able to revaporize due to the shift of the phase envelope. (Phase 2)
- Condensate banking still occurs in the presence of immobile water. Water did not have any measurable effect on the compositional variation of the gas condensate in the experiments done here. (Phase 2)
- (Interim) Condensate banking can be reduced by minimizing the pressure drop below the dew-point, either by producing the well slowly or by applying partial pressure maintenance using gas injection. (Phase 3)

Thank you!

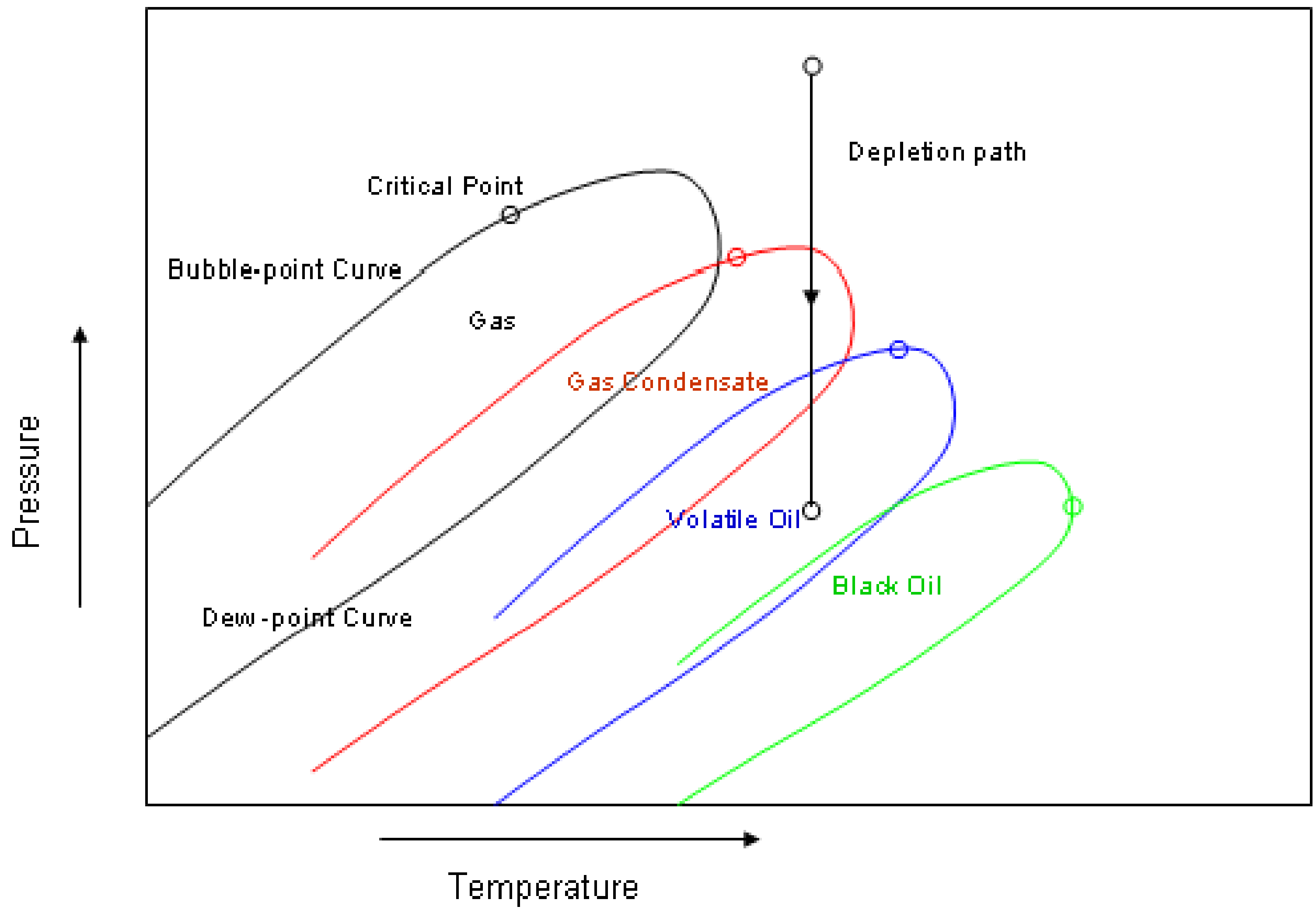
Questions, suggestions and discussions

How the Productivity is Lost?



• During production, if the pressure near the wellbore falls below the dew point pressure, condensate drops out and builds up a condensate bank around the producing well. This will decrease the liquid recovery and reduce gas productivity due to relative permeability effects.

What is Gas-Condensate?



Model of Gas-Condensate Banking

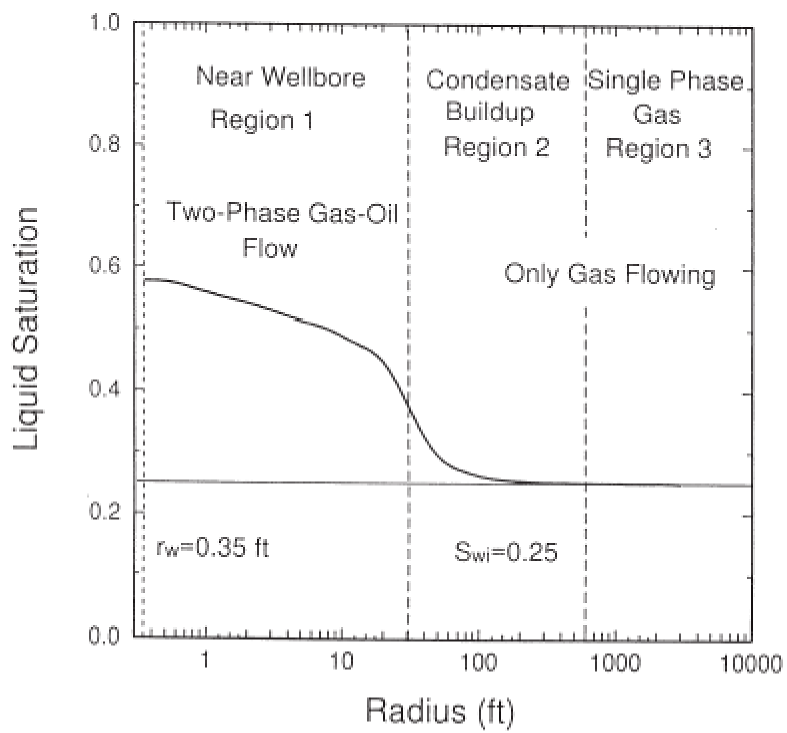
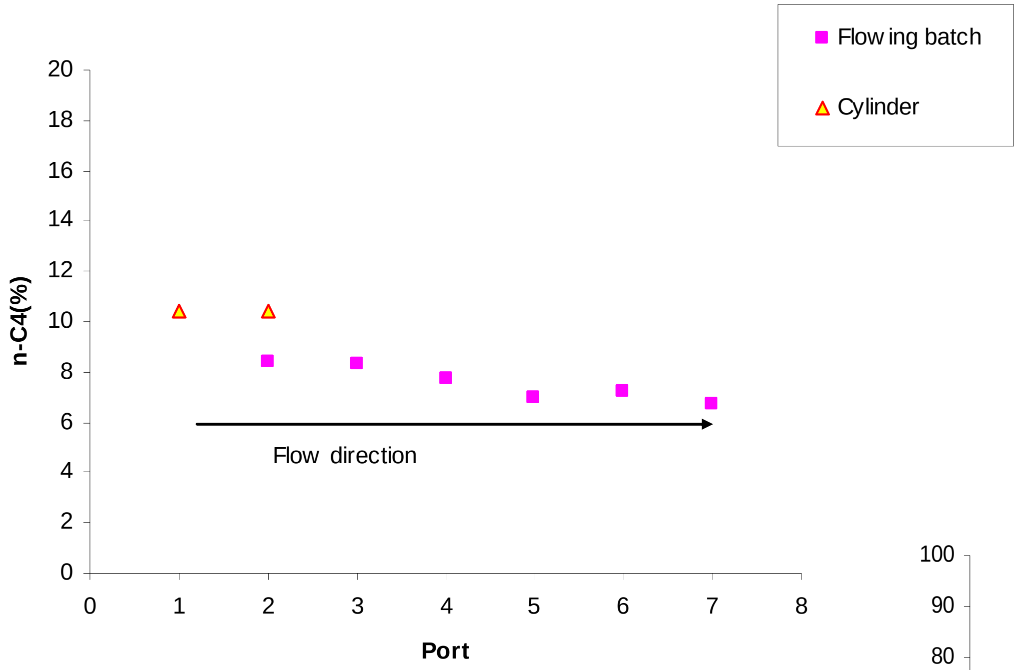
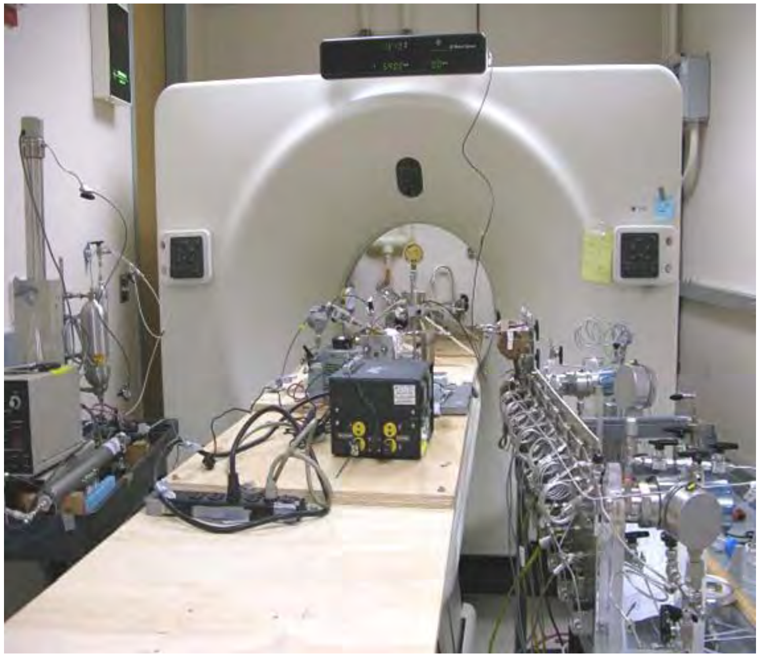


Fig. 1—Three regions of flow behavior in a gas-condensate well.

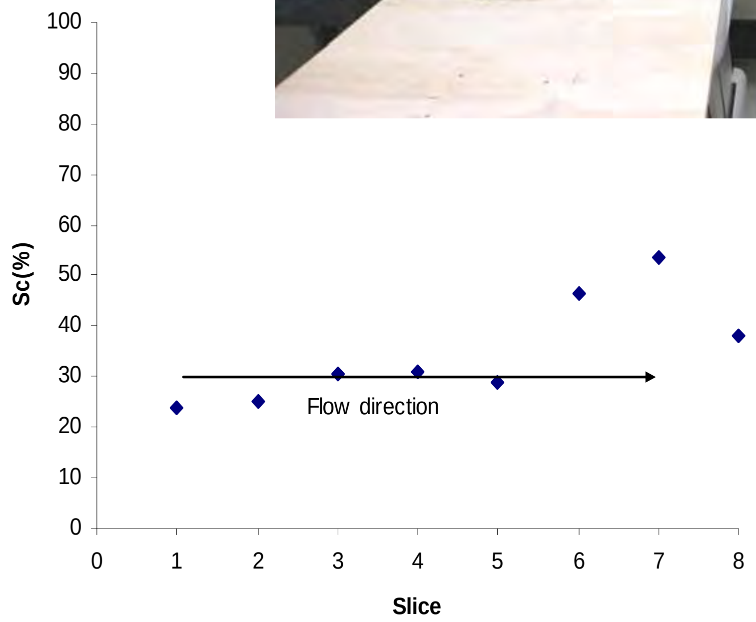
- Fevang and Whitson (SPERE, 1996) proposed an accurate yet simple model of a gas-condensate well undergoing depletion and it has been used commonly in literature.

Saturation Measurement using CT Scanner

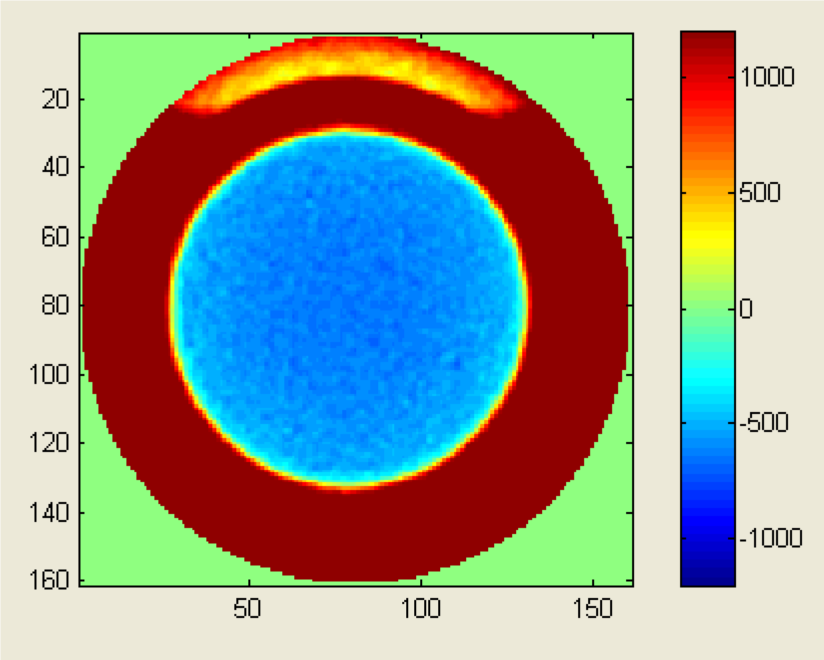


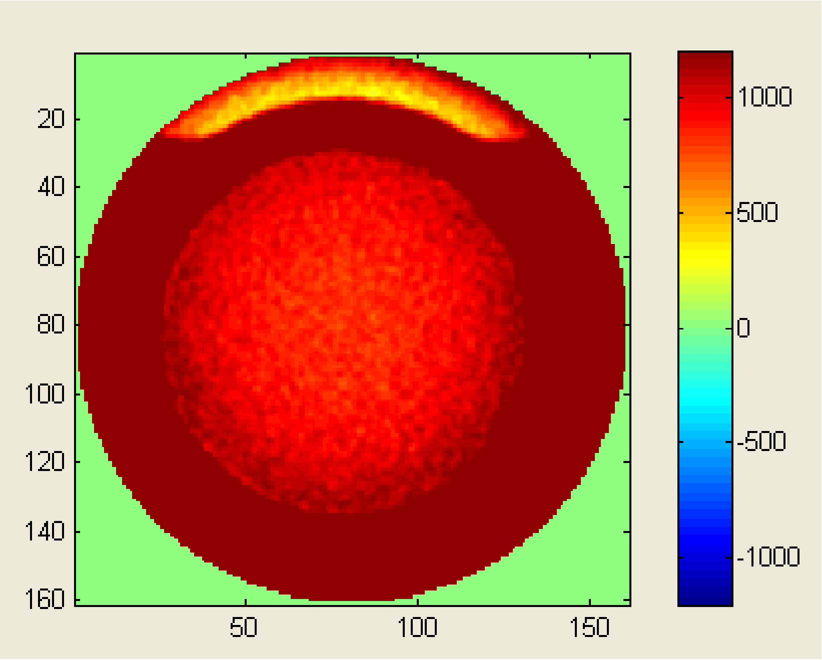


$$S_c = \frac{CT_{\exp} - CT_{gr}}{CT_{cr} - CT_{gr}}$$



Saturation Measurement using CT Scanner (2)





- Use of titanium core holder has caused beam hardening which affects the saturation measurement.
- *CT* values of air (left image) and water (right image) inside the titanium core holder were falsely measured as -625 H and 837 H respectively whereas the correct values are -1000 H and 0 H respectively.

Compositional Variation Model

- Model

$$\frac{\partial z_i}{\partial t} = A_i \frac{\partial p}{\partial t} + B_i \left(\frac{\partial p}{\partial r} \right)^2$$

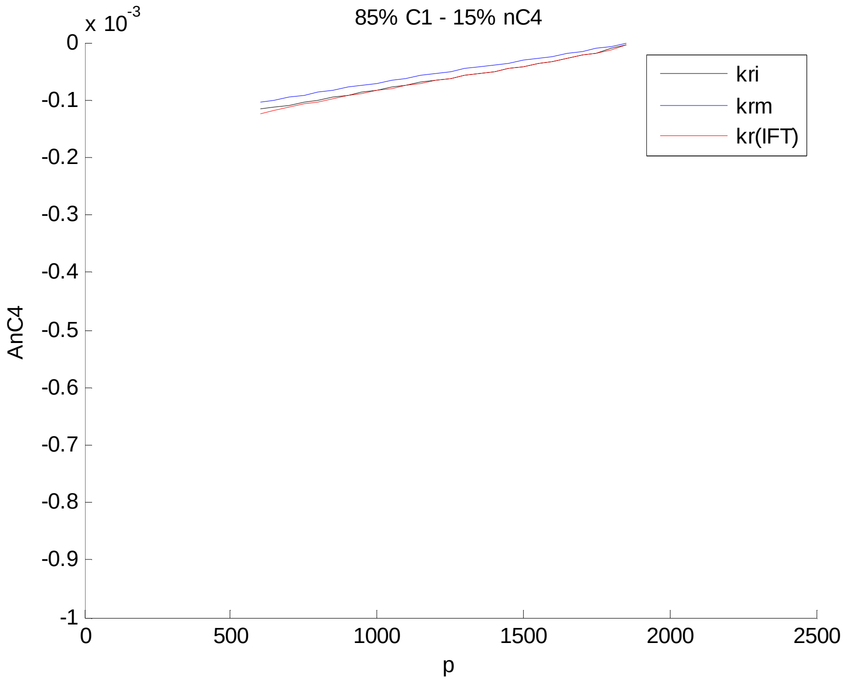
where:

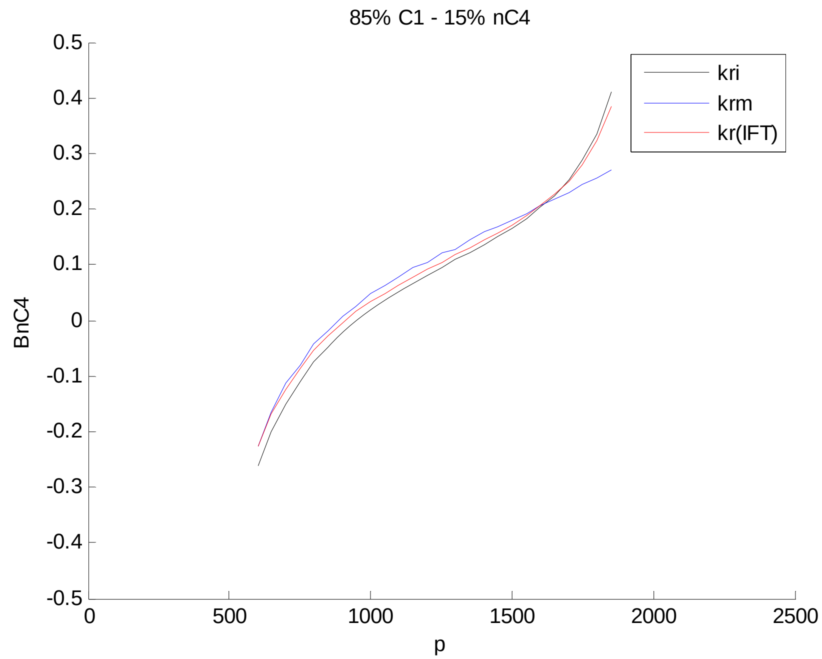
$$A_i = \left(\frac{m_i}{m} - z_i \right) \frac{\partial \ln G}{\partial p} \qquad B_i = \frac{m_i}{\phi G} \frac{\partial}{\partial p} \left(\frac{m_i}{m} \right)$$

$$m_i = \sum_{j=1,N_p} x_{i,j} \rho_j \left(k \frac{k_{rj}}{\mu_j} \right) \qquad m = \sum_{i=1,N_c} m_i$$

$$G_i = \sum_{j=1,N_p} x_{i,j} \rho_j S_j \qquad G = \sum_{i=1,N_c} G_i$$

A_i and B_i





- A_i is always negative and much smaller than B_i.
- B_i is positive at high pressure and negative at low pressure.

Compositional Variation Model Analysis

$$\frac{\partial z_i}{\partial t} = A_i \frac{\partial p}{\partial t} + B_i \left(\frac{\partial p}{\partial r}\right)^2$$

Near well $\frac{\partial p}{\partial t}$ is small and $\frac{\partial p}{\partial r}$ is large, $B_i \left(\frac{\partial p}{\partial r}\right)^2$ dominates.

Far away from the well , $A_i \frac{\partial p}{\partial t}$ dominates.

1. Well produced at constant BHP $\frac{\partial p}{\partial t} = 0$: $\frac{\partial z_i}{\partial t} = B_i \left(\frac{\partial p}{\partial r}\right)^2$

2. Shut in the well: (∂p/∂t) will be positive, $A_i(\partial p/\partial t)$ negative.
However, this term is insignificant and $B_i(\partial p/\partial r)^2$ term is still dominant.

B_i is positive if the pressure above a certain threshold so $\frac{\partial z_i}{\partial t}$ is positive, hence z_i increases.