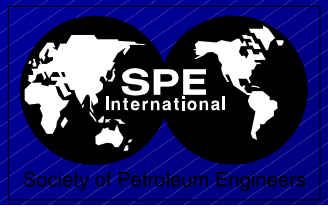
# SPE 63086

(originally SPE 49269)

# Miscibility Variation in Compositionally Grading Reservoirs

Lars Høier, SPE, Statoil

Curtis H. Whitson, SPE, NTNU and Pera



# BACKGROUND

Miscible gas injection processes are well documented in the literature.

Compositional variation with depth has also been studied the past 20 years.

However, almost nothing in the literature is found on the variation of miscibility conditions with depth in reservoirs with compositional gradients.

# PURPOSE

Intuitively, it is difficult to picture the variation of MMP with depth for a reservoir with varying composition and temperature.

This study shows that a simple variation does not exist, but that certain features of MMP variation are characteristic for most reservoirs.

# Fluid Systems

- Three reservoir fluid systems, each with significant compositional grading.
- Lean and enriched injection gases.
- Peng-Robinson EOS, typically with 15 components, five C7+ fractions, and *no* grouping of intermediates.

# Calculating Miscibility Conditions

## *A Multicell Algorithm Developed by Aaron Zick*

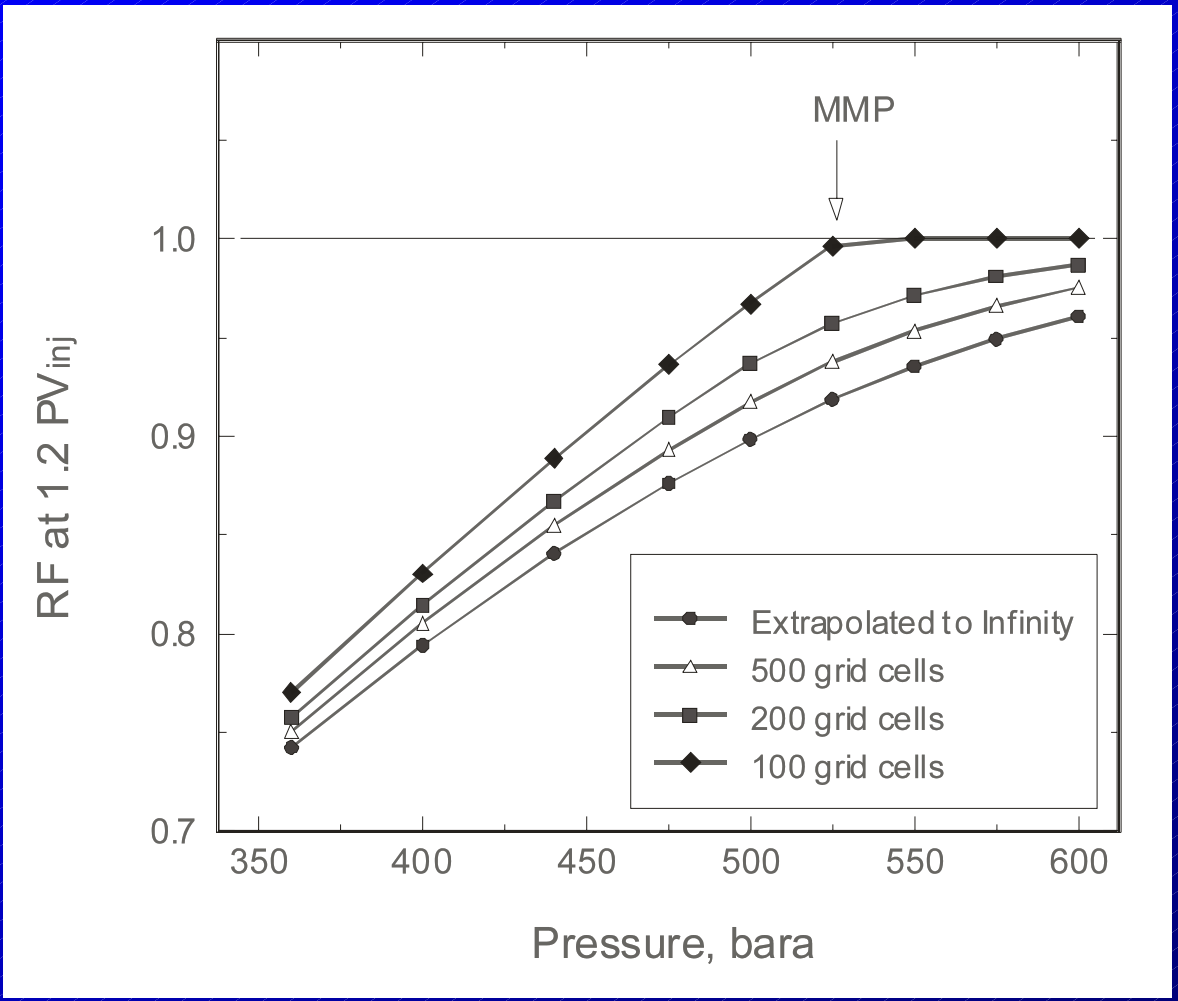
- **Defines "true" minimum miscibility conditions (pressure or enrichment)**

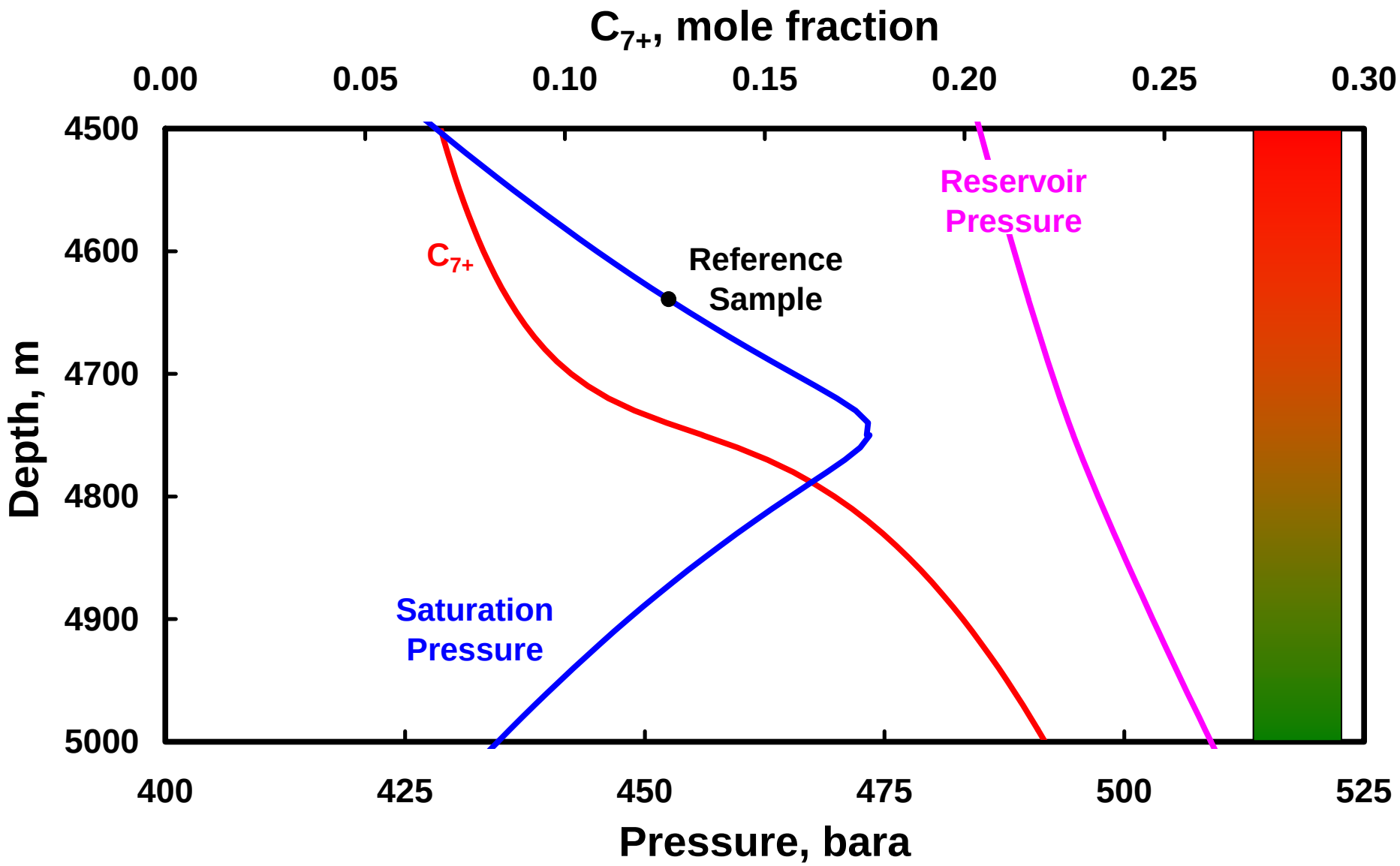
- **Identifies the developed-miscibility mechanism**
  - **Condensing/Vaporizing Drive (C/V)**
  - **Vaporizing Gas Drive (VGD)**
  - **Condensing Gas Drive (CGD)**
  - **First Contact Miscible (FCM)**

# Calculating Miscibility Conditions

- Zick algorithm is fast and uses an internally-consistent numerical solution.
- Zick algorithm has been verified in this study by numerous 1D numerical (“slimtube”) simulations for a large range of fluid systems, injection gases, and miscible mechanisms.

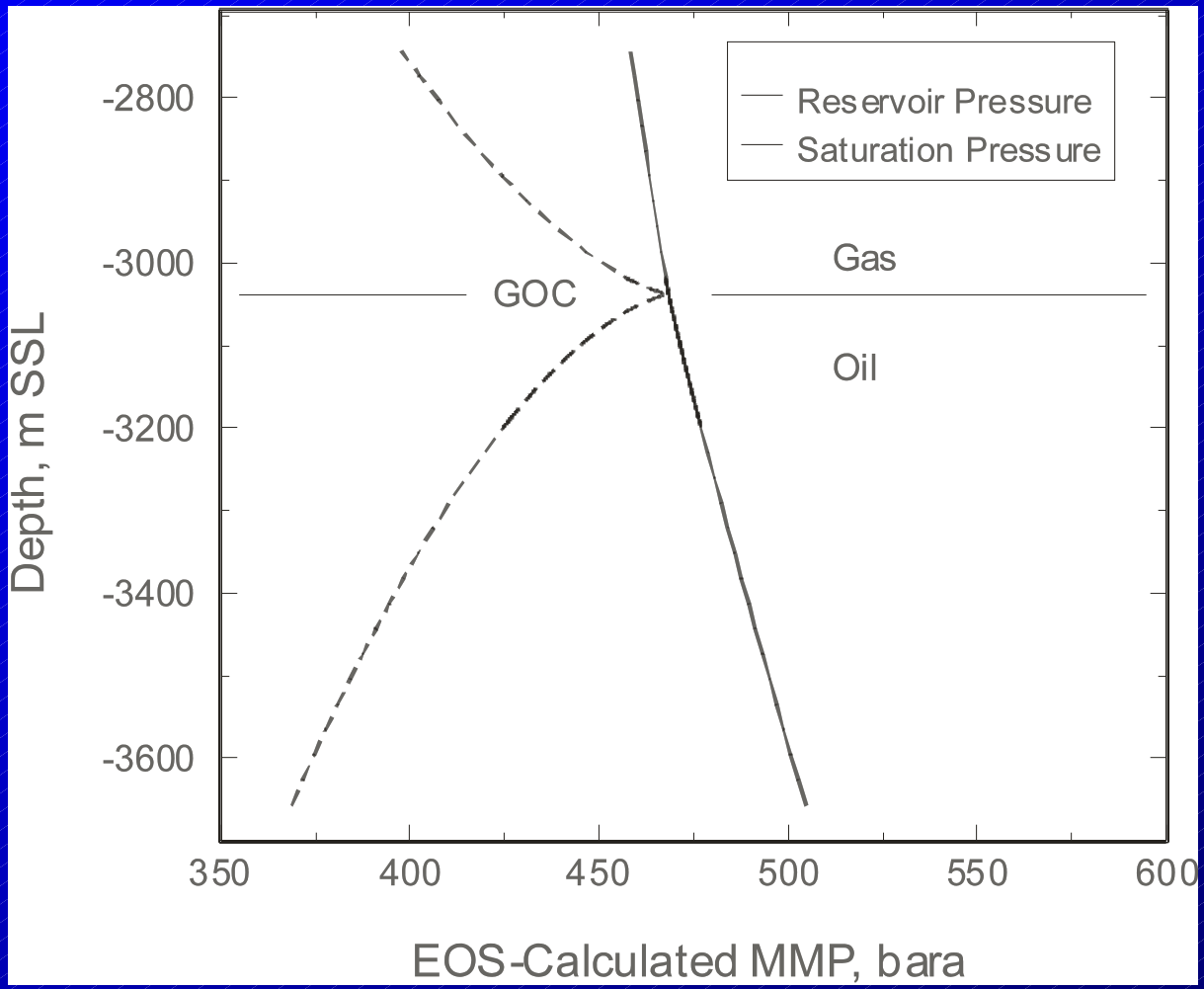
# MMP from Slimtube Simulations




$C_{7+}$, mole fraction
0.00
0.05
0.10
0.15
0.20
0.25
0.30
4500
4600
4700
4800
4900
5000
Depth, m
$C_{7+}$
Reference
Sample
Reservoir
Pressure
Saturation
Pressure
400
425
450
475
500
525
Pressure, bara

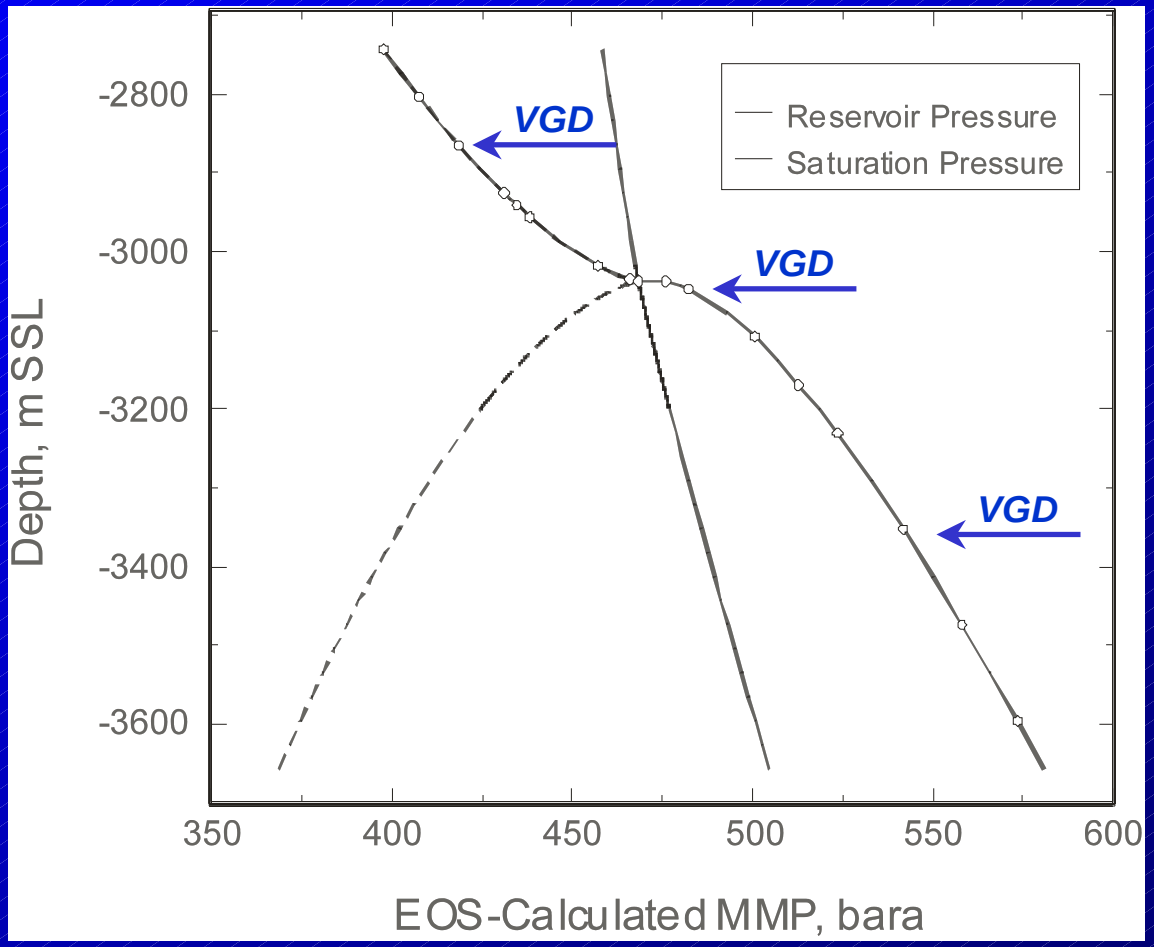
# MMP versus Depth

## *Example 1*



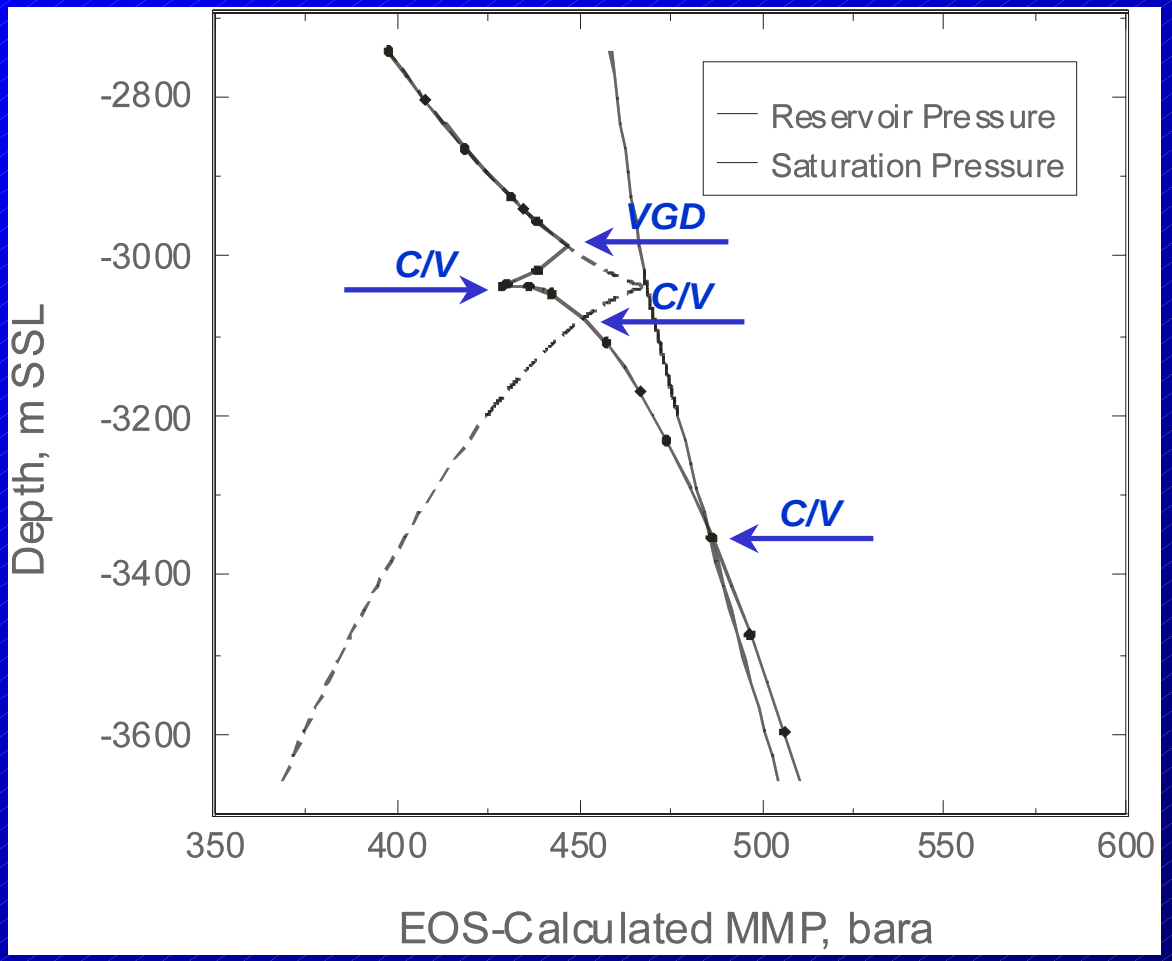
# MMP versus Depth

## *Example 1 – Lean Gas Injection*



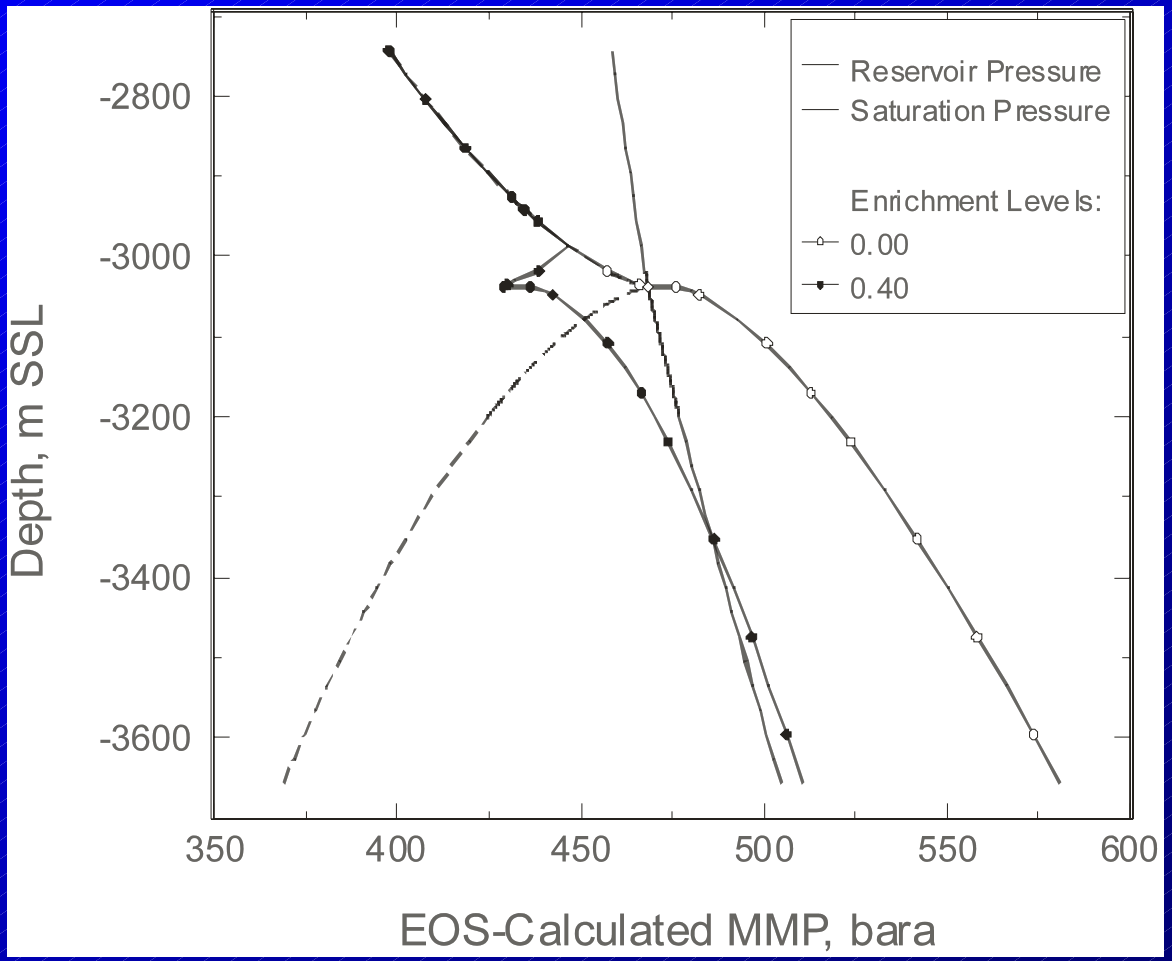
# MMP versus Depth

## *Example 1 – Enriched Gas Injection*



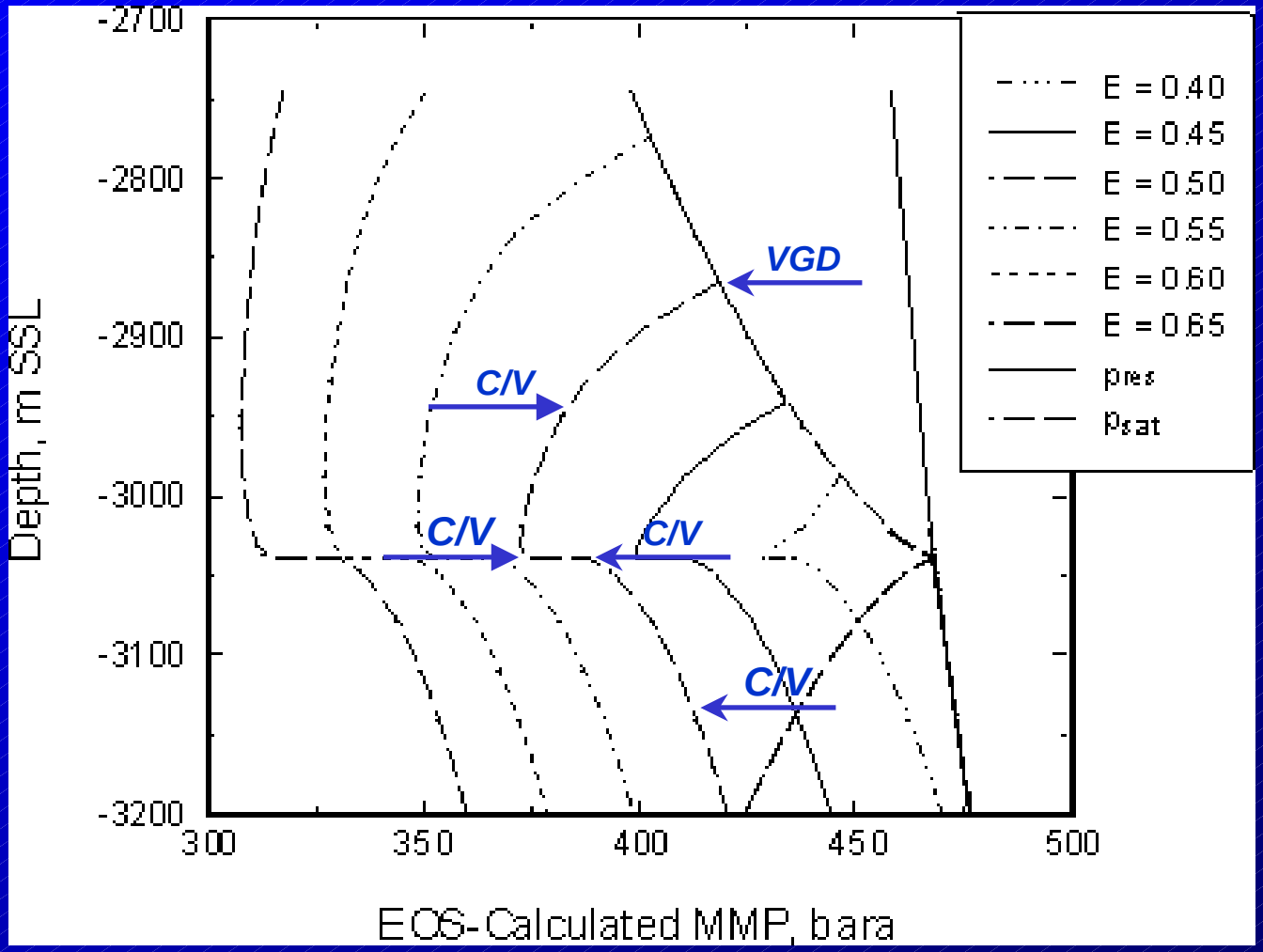
# MMP versus Depth

## *Example 1*



# MMP versus Depth

## *Example 1 – Varying Enrichment*



# ***Oil Reservoirs – Summary***

**MMP always increases with depth, both for VGD and C/V mechanisms.**

- **VGD MMP is always greater than or equal to the bubblepoint pressure.**
- **C/V MMP can be greater than or less than the bubblepoint pressure.**

# *Gas Condensate Reservoirs – Summary*

**In gas condensate reservoirs, MMP variation with depth follows exactly the dewpoint variation with depth**

**only**

**when miscibility develops by a purely VGD mechanism.**

# ***Gas Condensate MMP – Summary***

**For a depleted gas condensate reservoir,**

***the composition of the retrograde condensate***

**controls the C/V MMP.**

# ***Gas Condensate MMP – Summary***

**MMP can be *significantly lower* than the dewpoint pressure.**

**This requires that the C/V mechanism exists, which usually results from the injection of an enriched gas (or $CO_2$ ?).**

# C/V Mechanism in Gas Condensates below Dewpoint Pressure

**Key features in 1D slimtube simulations:**

- **An oil bank develops, increases in size, and propagates through the system.**
- **The miscible front is located on the ‘’back side’’ of the saturation bank, leaving behind a near-zero oil saturation.**

# C/V mechanism in a depleted system

*(gas condensate reservoir, 0.7 PV injected)*

# Oil bank development

*(depleted gas condensate reservoir)*

# CONCLUSION,
# MMP below Dewpoint Pressure

**Dispersion has a strong influence on the development of miscibility by the C/V mechanism for lean gas condensates.**

# Elimination of numerical dispersion

*(gas condensate reservoir)*

# Slimtube displacment STO recoveries

*(gas condensate reservoir)*

# CONCLUSION,
# MMP in depleted reservoirs

**For a depleted retrograde condensate reservoir, the composition of the retrograde condensate at the start of a cycling project controls the C/V MMP.**

# CONCLUSION,
# MMP in depleted reservoirs

**Simple 1D slimtube simulations demonstrate that slug injections as small as 10% PV of enriched gas in depleted gas condensate systems can develop miscibility at the same conditions as continuous enriched-gas injection.**

# Recomendation
# MMP in depleted reservoirs

For depleted rich gas condensate reservoirs:

- Perform 3D compositional simulations to evaluate miscible gas (slug) injection versus traditional dry gas injection.

- Measure the MMP by traditional slimtube displacement

# Key Observation

**Miscibility variation with depth due to gravity-induced compositional gradients can be significant.**

**The miscibility variation depends strongly on the mechanism of developed miscibility:**

- **Condensing/Vaporizing Mechanism ( C/V )**
- **Vaporizing Gas Drive ( VGD )**

# NOTE

**If the condensing/vaporizing mechanism exists, then the true C/V MMP will always be less than the VGD (vaporizing) MMP.**

# MMP variation with enrichment

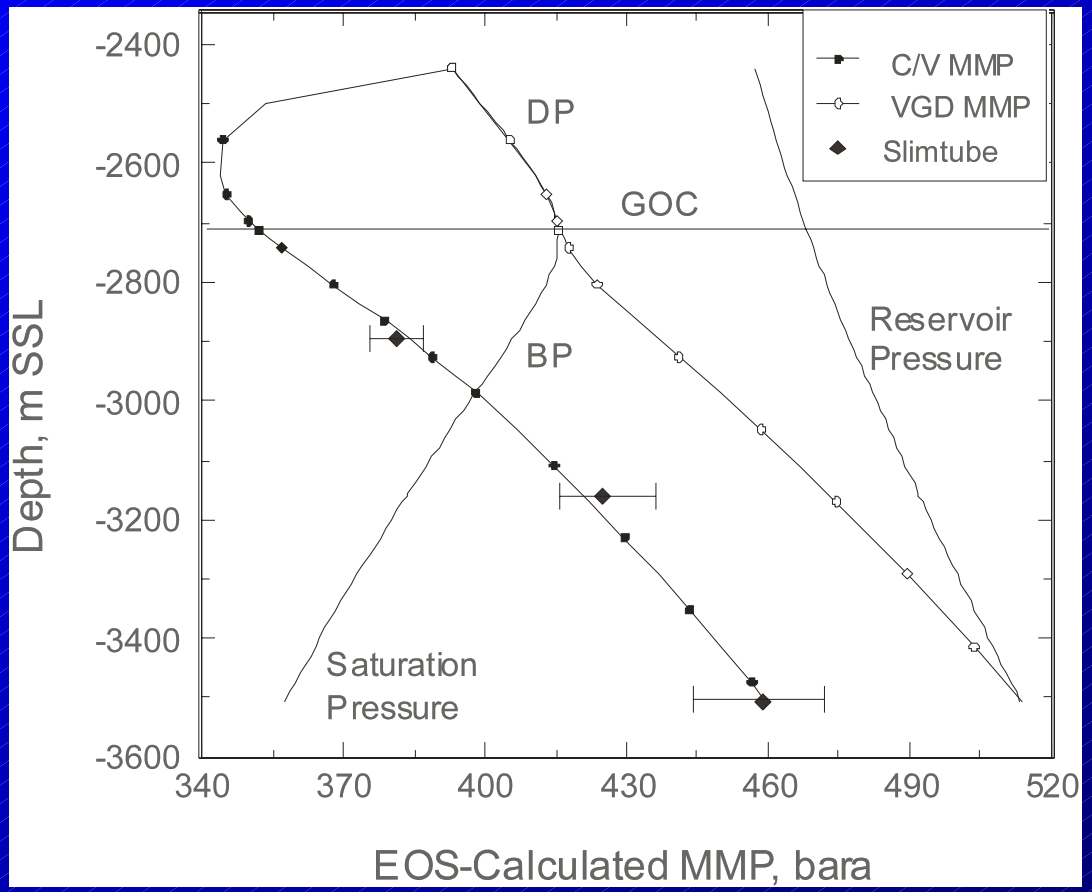
*at a specific depth in an oil zone*

# Vaporizing MMP variation with depth

## (*dry gas injection in SVO reservoir )*

# MMP versus Depth

## *Example 2*



# Gas Condensate Reservoirs – Summary

- MMP on the gas side of the GOC is less than or equal to the MMP on the oil side of the GOC.
- MMP may decrease slightly at depths above the GOC until a minimum is reached
- MMP increases until the condensing part of the mechanism disappears and the MMP equals the dewpoint (VGD MMP) variation with depth.