Note Title 5/13/2016

THURSDAY REVIEW

* EOS MODEL TUNING

- QC / Entry / QC of Compositions & PVT data to PVT program
- Default EOS predictions – Assessment / QC
- Select Pool of Tuning Variables
  - Min / Max
  - EOS C_{7+} | C_{N+} T_{ci} p_{ci} ω_i
  - $\gamma_i = f(M_i, C_f) \rightarrow s_i \rightarrow \rho_o$ match
  - BIPs $C_1 - C_{7+}$ | non-HC for gas inj PVT | HC-HC (C_{7+}-C_{7+})
  - Sample-specific Composition Variables: M_{N+} | GOR | z_{N+} ( )
- Systematic / Journaled set (10s – 100s) Regressions
  - Weight factor adjustments
  - Variable selection

$$WSSQ(V_j) = \sum_i (r_i \overset{\text{user controlled}}{w_i})^2$$

  - DONE!

(v_{cvis}) (v_c)
(Z_{cvis}) $(\underline{Z_c})$

$$r_i = \frac{d_{ci} - d_{mi}}{d_{ref\,i}}$$

- Viscosity Tuning
  - LBC C_{7+} fraction $\overbrace{Z_c \text{ or } v_c}$ values | $\underline{\mu_{wi}(T, M_i, \gamma_i)}$
  - LBC coefficient adjustments a_3 a_4 only
  - Always include both μ_g and μ_o
  - Target: All (90-95%) data ± 5-10% unbiased
  - Oil Reservoirs w/ large API variation: C_{N+} < L(P) $\mu\uparrow$; H(A) $\mu\downarrow$

* Black-Oil PVT (BOPVT)

- Oil Phase: $B_o(p)$ $R_s(p)$ $\mu_o(p)$ — $S \neq U$ @ p
- Gas Phase: $B_{gd}(p)$ $r_s(p)$ $\mu_g(p)$ — $S \simeq U$ @ p

} $\rho_{\bar{g}}$ $\rho_{\bar{o}}$ common

B_{gd} "= B_g" (In books) Ch.7

- $\rho_g(p)$ & $\rho_o(p)$ $= f(\text{BOPVT}, \underbrace{\rho_{\bar{g}}, \rho_{\bar{o}}}_{\text{optimize!}})$

- BOPVT $= f$ (Surface Process) – Particularly r_s & higher R_s, B_o
  EOS | $\tilde{K}_i$ | $RF_{\bar{o}i}(z_w)$

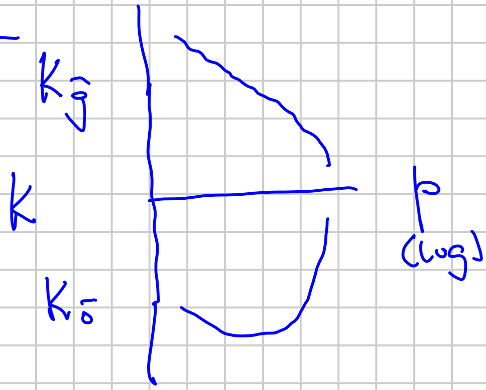
- Consistency Issues e.g. negative compressibilities
- Extrapolation to higher saturation pressures

SPE 63087, 109596

⊙ Relation to Compositional:

Black-Oil PVT	Compositional PVT
$\bar{g}$ $\bar{o}$	$\sim$ i
Total GOR	$\sim z_i$
R_s	$\sim x_i$
r_s	$\sim y_i$

$$K_i = f(R_s, r_s)$$



$\underbrace{GOR}$, $\underbrace{R_s, r_s}$, $\underbrace{B_o, B_{gd}}$ $\sim \underbrace{V_{ro}} = V_o / V_t \sim \underbrace{S_o}$ $\qquad z_i \quad K_i \quad \rho_g \ \rho_o$

R_s B_o $\} \ \underbrace{\rho_{\bar{g}} \ \rho_{\bar{o}}}$ $\sim \rho_o$

r_s B_{gd} $\sim \rho_g$

$\mu_o(R_s, p) \sim \mu_o(x_i, p)$

$\mu_g(r_s, p) \sim \mu_g(y_i, p)$

5-6

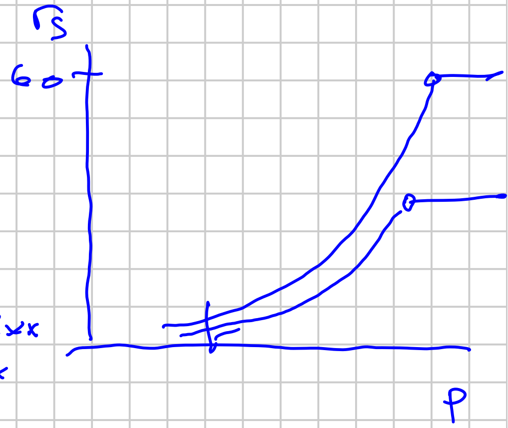
BO PVT Issues

BO vs EOS Reservoir Simulation

(Depletion + WF) BO ✓ = EOS

Except (1) μ_o (IJK) API-Tracking $\sim$ vs EOSxx
EOS3 $\sim$ EOSxx

(2) Leaner G.C. fields r_{si} (I J K)



✓ Gas Injection: Gas Cycling G.C. BO = EOS $p_R > p_d$

EOS (3-5 C_{7+}) $p_R < p_d$

Oil EOR

Relevant Sector Model

Check EOS vs BO

20-30 slower 2-3 slower

EOS Simulator CPU Time $f(N_c)$ vs BO

- – Impes
- – Implicit (Huge Storage Issues)
- – AIM

PSEUDOIZATION (LUMPING) Coats 1983 (85)

Simulating Gas and Res

EOSX ← $\underbrace{\text{EOSXX}}$ [Tuned]

↑

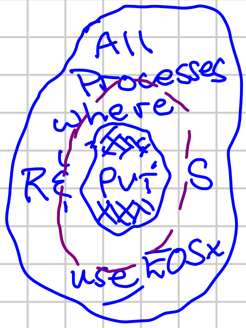
< 10 > 10

(15–40)

- $\underbrace{\text{EOSX}}$ ≃ $\underbrace{\text{EOSXX}}$ Goal

- Reliable Wide (p-T-z) Space

↳ Large PVT Data Base d_i^{EOSxx}



1000s

$$\min WSSQ(V_L) = \sum (w_i r_i)^2$$

Lumping Variables

$$r_i = \frac{d_i^{EOSX} - d_i^{EOSXX}}{d_{iref}}$$

Possibilities

① X value (3, 6, 9) ?

② Which components i in EOSXX(i) to lump into pseudocomponents I in EOSX(I)

③ $\bar{M}_{N2C1}$ $\bar{p}_{cN2C1}$ $(\bar{T}_c \quad \bar{\omega} \quad \bar{Z}_{cvis} \quad \bar{s})_{N2C1}$

- Coats gives the method ✓

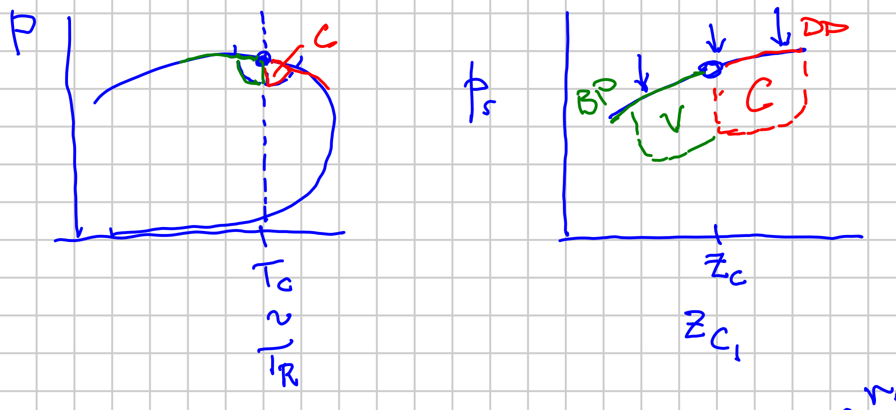
Need a "Mixing" "Averaging" Composition "Lumping"

$\tilde{z}_i$ (EOSxx)

Gas EOR PVT Tests

- Miscible Gas Displacement Processes
  (Tip of the Nose where $k_i \to 1$)
  - "Near-critical phase behavior" dominating the development of miscibility in the reservoir.
  - On each side of the critical state

$T < T_c < T$ At the front



small Δp
V_{ro} $0 \to 50\%$

complex phase behavior
- retrograde condensation
- severe vaporization

$V_{ro} = 1 \to 0.5$
small Δp

Zick, Aaron 1986
ARCO | Exxon | BP 1980s

⇒ Consequently the PVT test needed to help tune our EOS to describe such phase behavior need to exhibit Critial / Severe Cond / Severe Vapori.

AND

using as fluids Reservoir Oil of Interest and Inj Gas(es) of Interest.

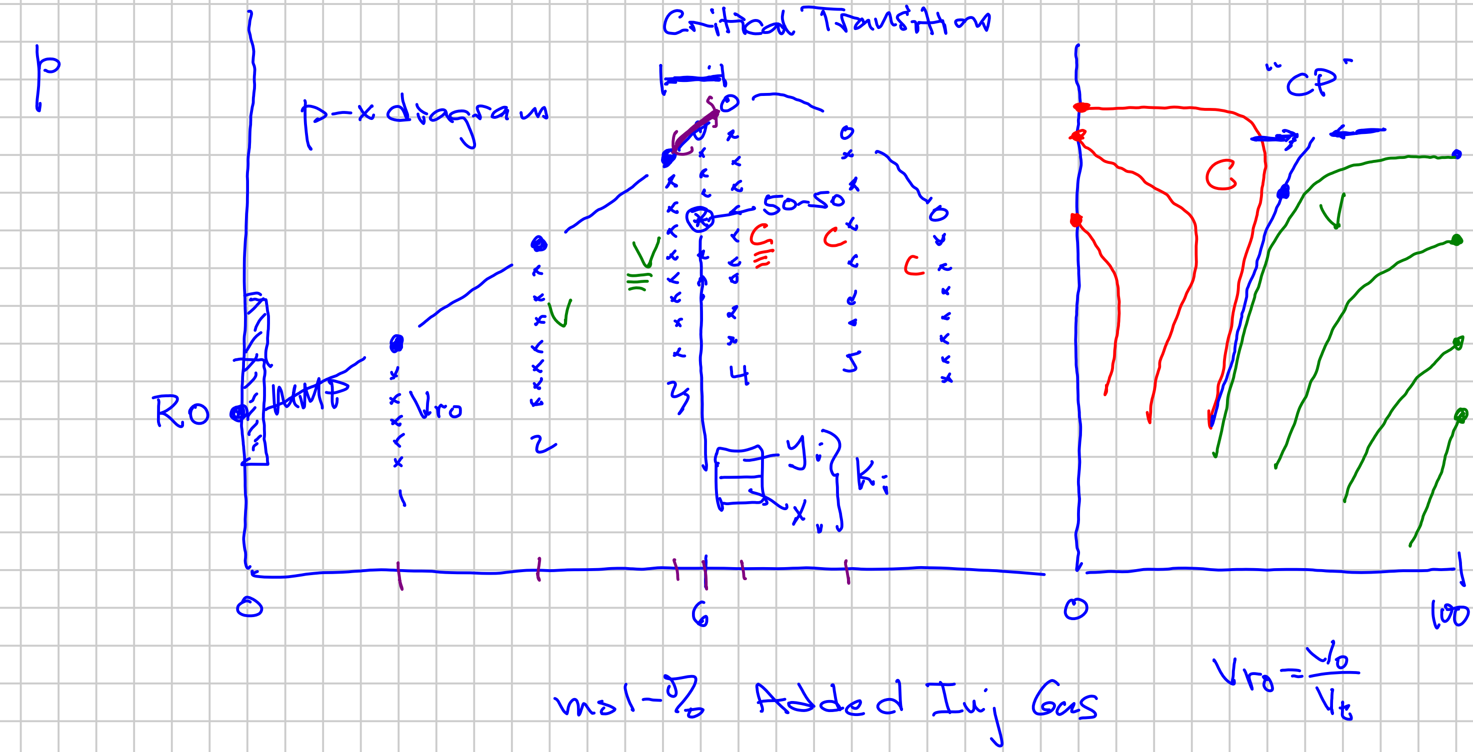
Special "Swelling" Test

Tells the lab a procedure

T_R = const

Windowed PVT Cell

5-6 Injections Mixtures RO + IG
3 BP mixtures   2-3 DP mixtures
2 (1 BP 1 DP) near-critical mixtures



$$V_{ro} = \frac{V_o}{V_s} \text{ or } \frac{V_o}{V_t}$$

Challenge: Design (of inj amounts) & Execution by Lab

Existing EOS

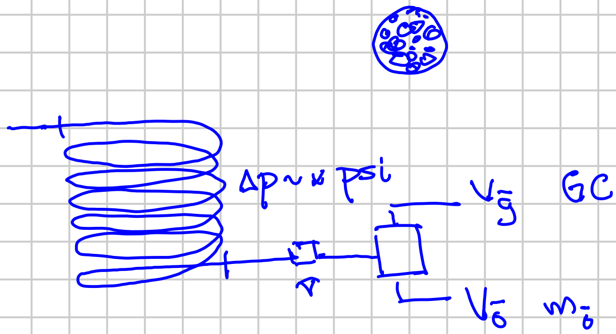
These data together with depletion data SEP ...,
to improve the EOS Model!

② Slimtube Test to determine the "true" minimum miscibility condition (MMP or MME)

Given Inj Gas

Given Pressure Inj Gas + Solvent (E)

$$\frac{V_{g\,inj}}{V_{pST}} = PV_{inj} \qquad PV$$



PV

GC $y_i(t)$

$RF_o \rightarrow 95^+\%$ Miscible

@ ~1.2 PV_{inj}

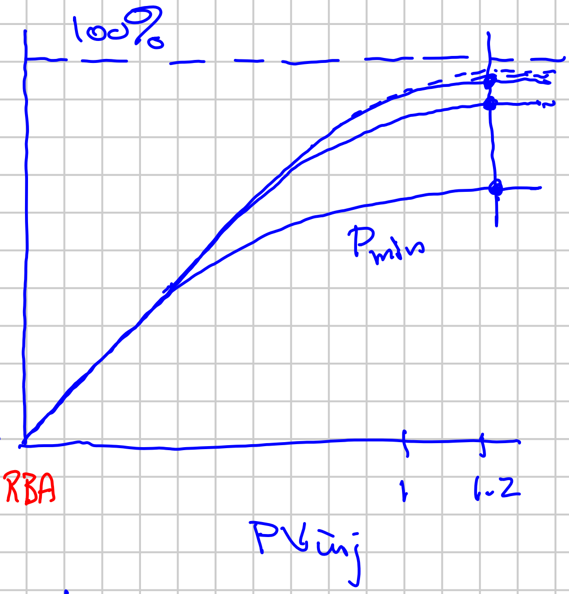
① Fill Slimtube pores with RO.

② Inject gas at a p ⇒ $RF_{1.2}$ RF_o

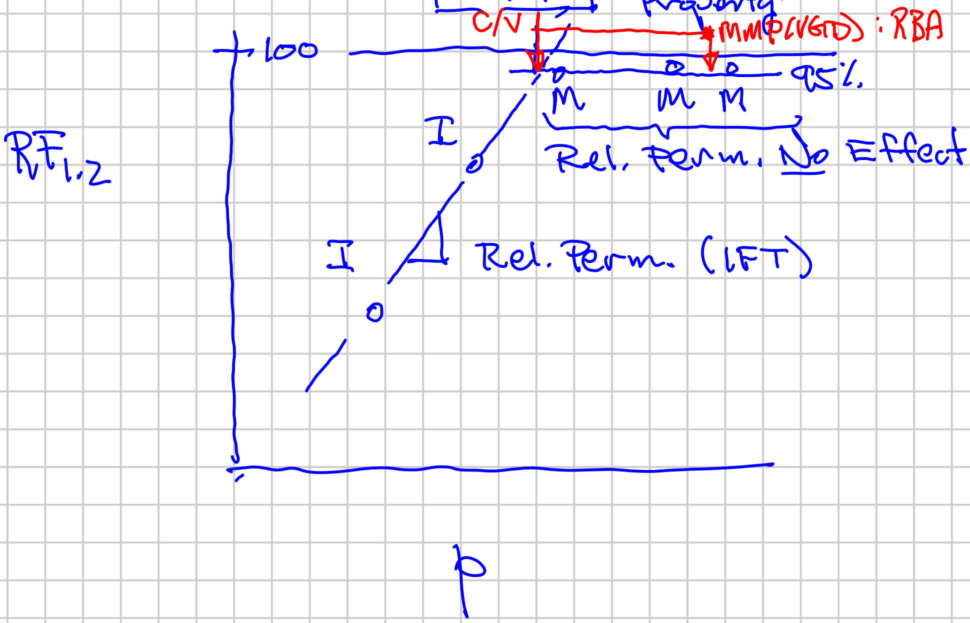
- 3–5 pressures

  or

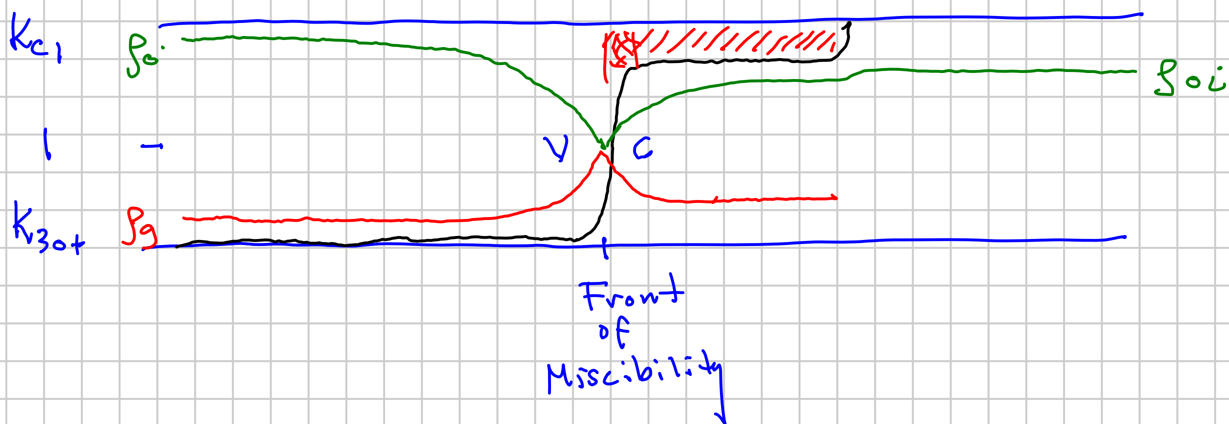
  3–5 Enrichment Levels @ p = constant



$\boxed{\sim MMP}$ Thermodynamic Property



$PV_{inj} = 0.5$



Hour-Glass Profile (C/V Miscible Gas

(Displacement Process)

Immiscible Gas Process PVT Tests

① Swelling / Viscosity Reduction

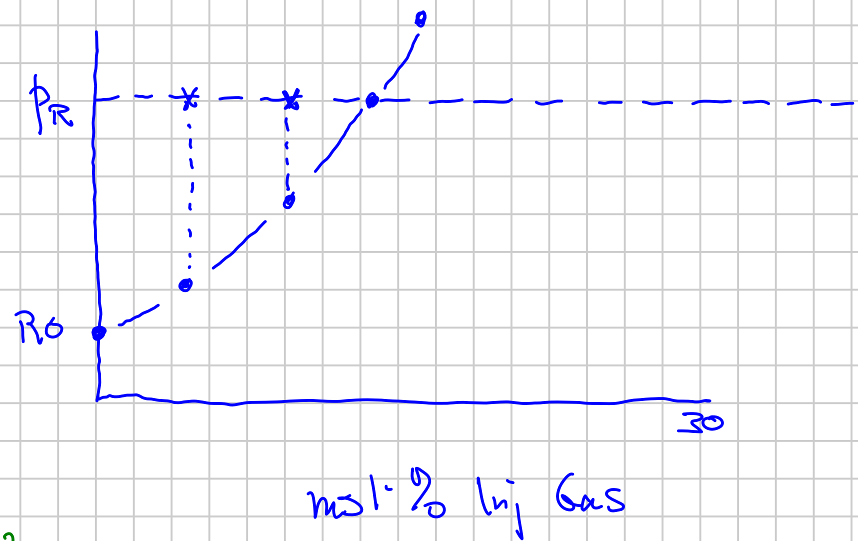
(Little-to-no vaporization of $C_7 \ldots C_x$ to gas)

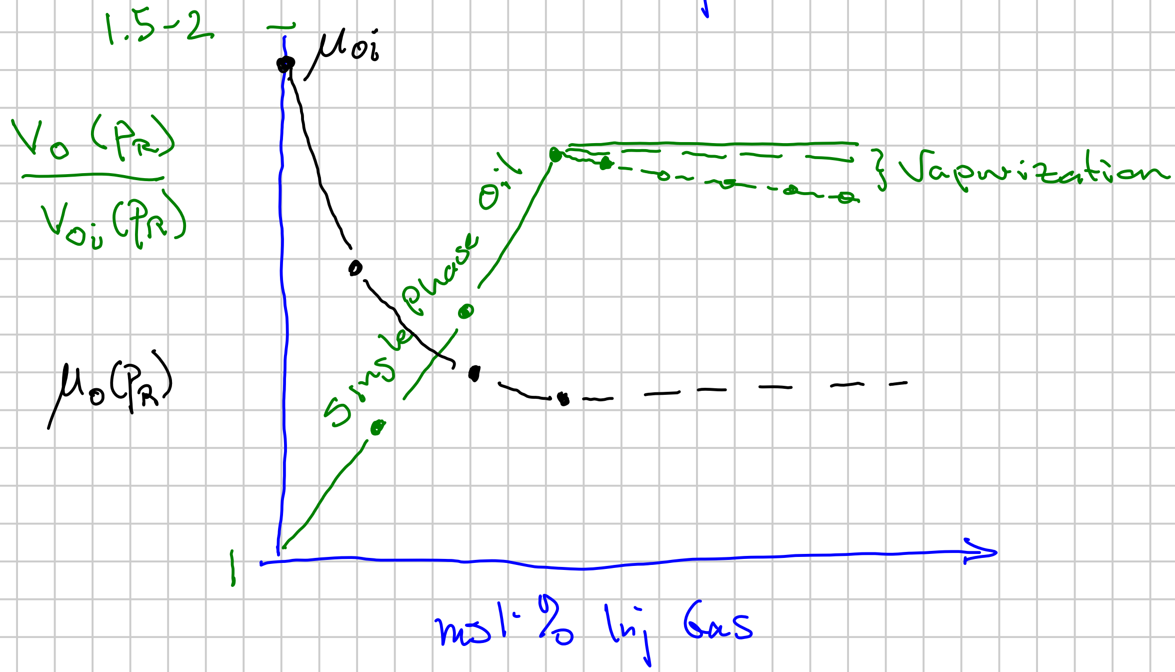
Lower P_R

Lower API 2x-30

Traditional Swelling Test

3-4 gas injections → Bubblepoints $P_{bmax} \sim P_R$, P_{inj}

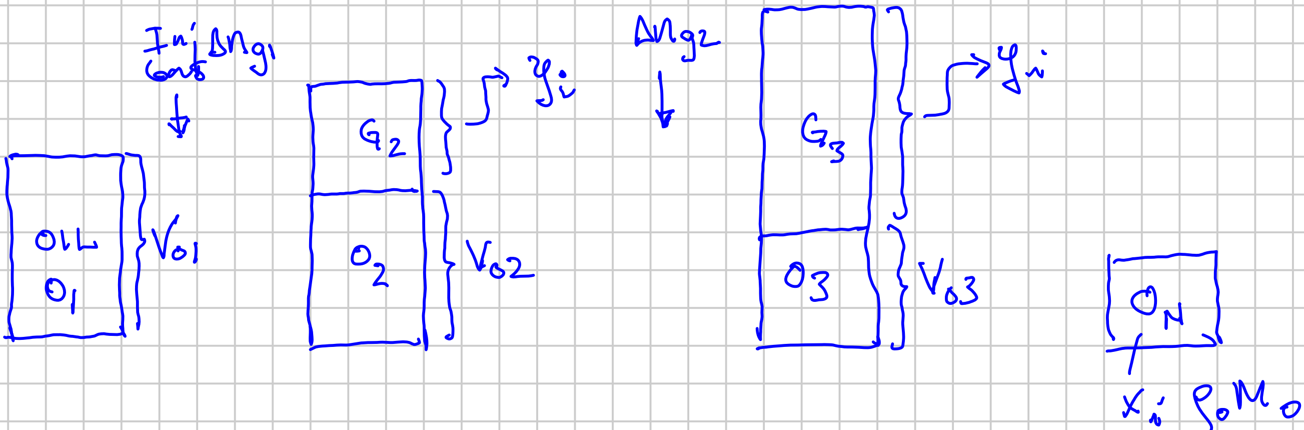




more C_7 C_8 C_9
Lighter Oils API > 35
$K_{i_{4+}}\uparrow$ Higher Press 3-5,000
Lean Inj Gas

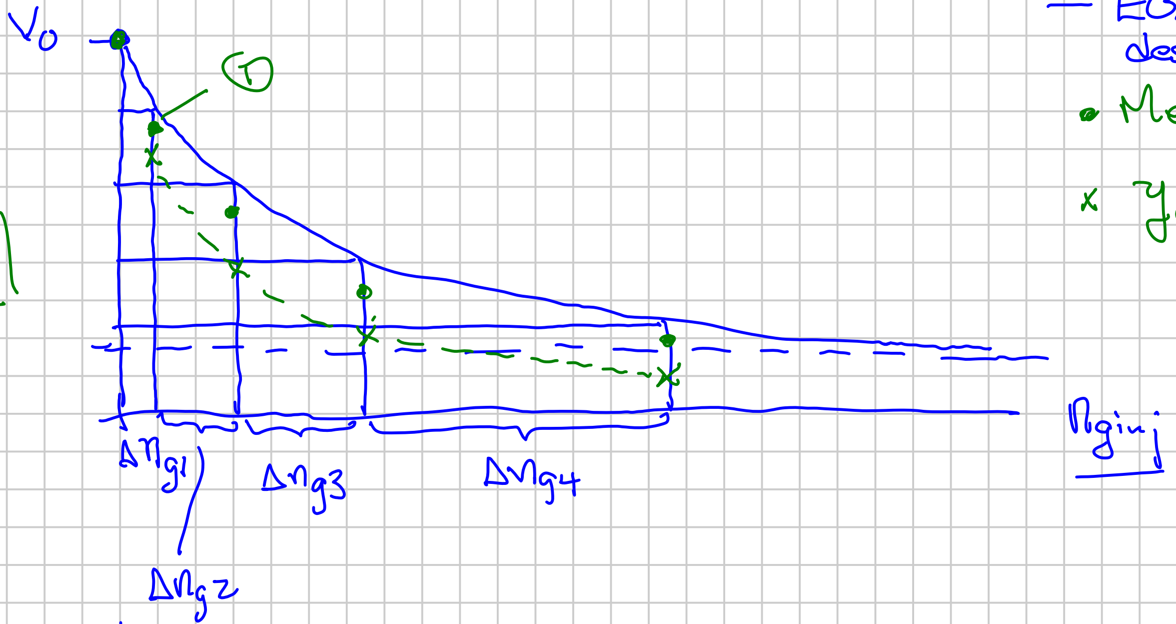
(2) Vaporization-Dominated Process

PVT Test : Backward Contact
At Point of Injection



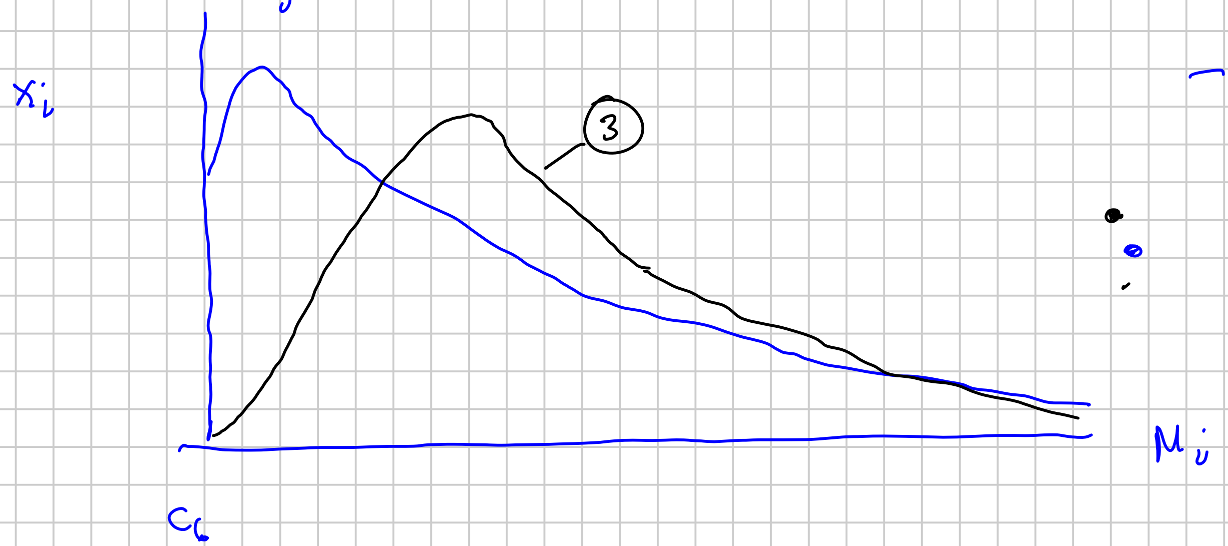
p = const
T_R

3-5 injections



(2) $\boxed{y_{6+}}$

— EOS design
• Measurements
x y_{6+}

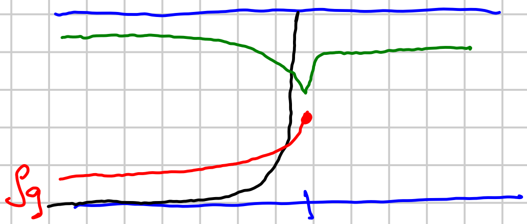


— RO
O_{Final}

Gas EOR Immiscible PVT Test

Forward Multi Contact - Most useful UGD

Near Miscible Process



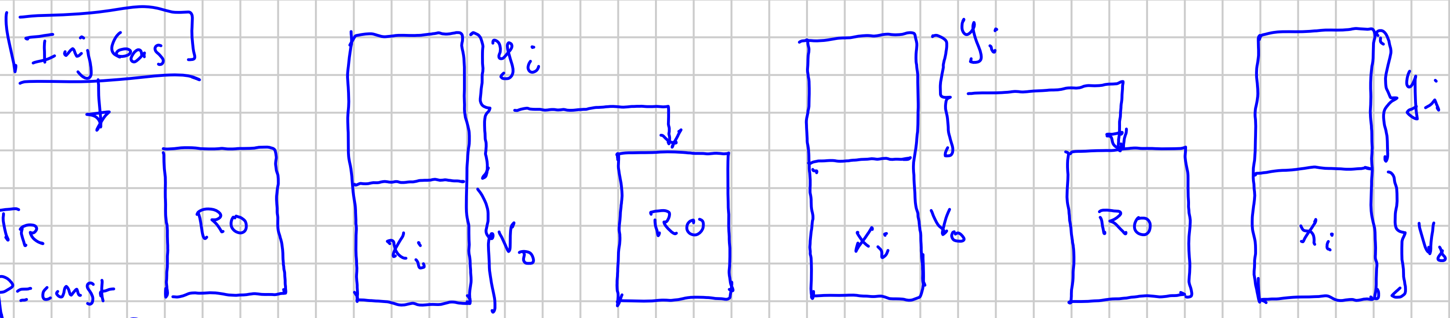
Gas Front

UGD

Lighter oils

Higher Pressures

y_{nf}



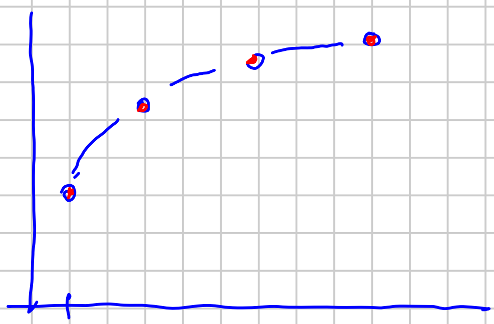
T_R

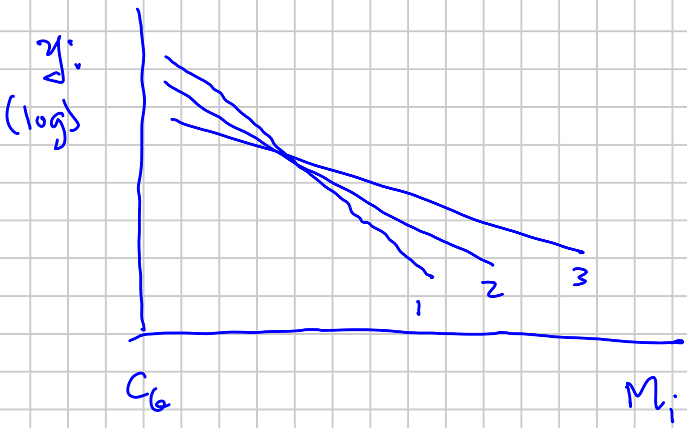
$P = const$

$\left[\begin{array}{l} P_{max} \\ P_{min} \end{array} \right]$

y_{6+}

p^*

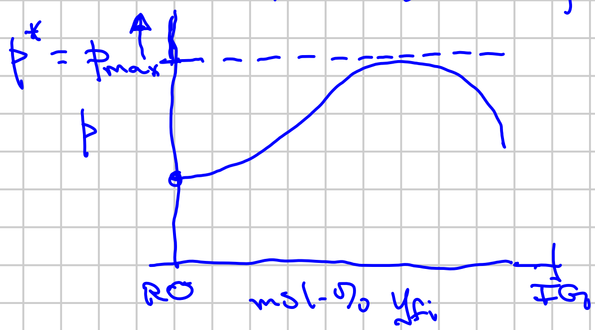




What P does the frontal gas y_{fi} become miscible with the RO

Each step

y_{fi}



EOS PVT simulators prediction of MMP MME

- Phaze Comp ⇒ True MMX

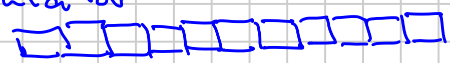
Surrogate 1D
eliminates
numerical
dispersion

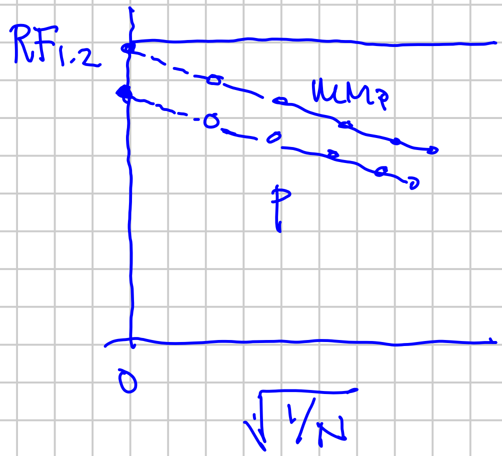
C/V

$\boxed{\text{UGD}}$ MMP

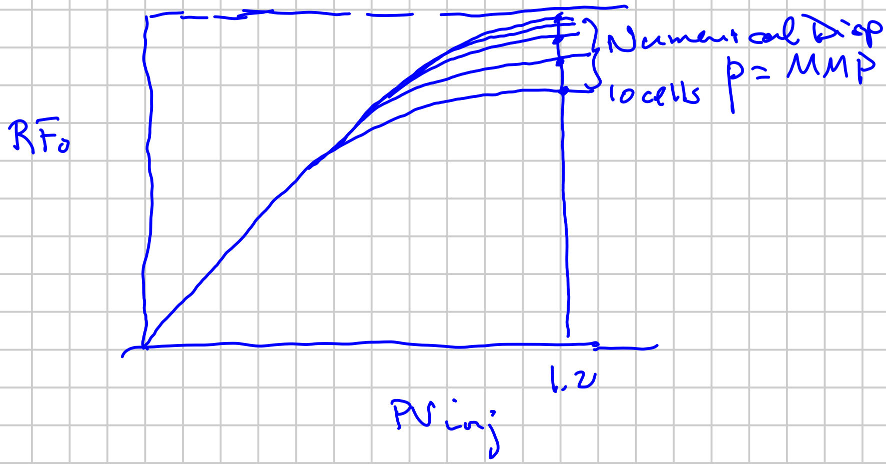
PVT cell

Simulate
like a 1D reservoir
simulator

"  "



RF1.2
MMP
P
0
√1/N



RFo
Numerical Disp
P = MMP
10 cells
1.2
PV inj

Vertical Compositional Gradients

– Equilibrium Criteria

$$\underbrace{\frac{dp}{dD} = \rho g}$$ Ensures $v_z = 0$ (Darcy)
Bulk flow

$\boxed{\text{Chemical-Gravity Equilibrium (Gibbs)}}$

What drives a component to move vertically or horizontally? Molecular Diffusion

$$v_i = D_i \underbrace{\frac{d\Phi_i}{dl}}_{0}$$
v_i: 0

Fick's eq.

Total Component Potential

$\Phi_{iz} = \mu_i + M_i g (D - D_{ref})$

$\Phi_{ix,y} = \mu_i$

$T = \text{const}$
$dT/dD = 0$

$$\underbrace{\frac{d\Phi_i}{dD} = 0} \Rightarrow \underbrace{\overset{EOS}{\mu_i}(P_{ref}, z_{ref,i})}_{@\,D_{ref}} = \mu_i(p(D), z_i(D)) + M_i g (D - D_{ref})$$

Know

$$v_{zi} = D_i \frac{d\Phi_i}{dD}$$
v_{zi}: 0, $\frac{d\Phi_i}{dD}$: 0

$p(D)$ $z_i(D)$ N+1 unknowns

N eqs.

$\sum z_i(D) = 1$

Muskat 193x : No, don't expect $z_i(D)$

EOS was not very good

Sage, Olds, Lacey 194x More rigorous EOS

Yes, do expect $z_i(D)$

1980 Schulte (Shell) < Brent UK / Birba Oman ⋮ } {P A}

$\bar{C}_7 < C_{7P}, C_{7A}$

$\bar{C}_8$

⋮

$\bar{C}_{N+}$

Cubic EOS (PR | SRK)

1990? Whitsun-Belery — Summary Paper w/ Calc's

Studied $T(D)$ Non-Isothermal

Maps out the magnitude of $z_i(D)$

Isothermal $dT/dD = 0$

Formalism of Gibbs out the window

Thermal Component Diffusion [Haase, Kemper

Firoozabadi

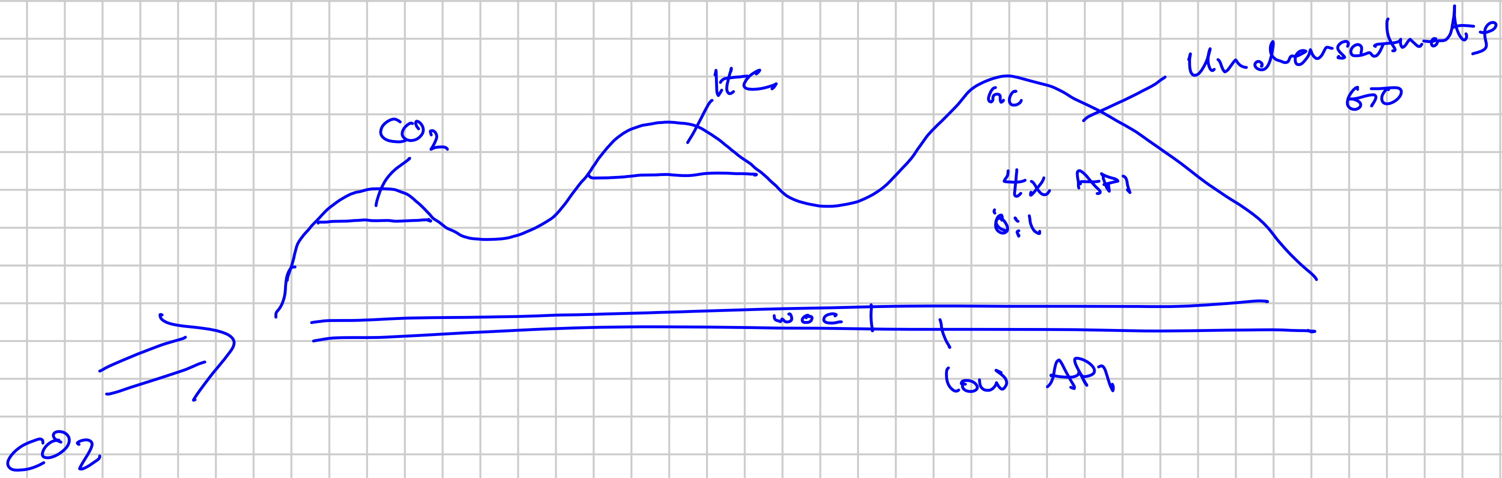
Calsep (PVTsim)

Pick your church ?

Michael Michelsen

If $z_{R_i}(D) \neq \overset{\text{CGE}}{z_{R_i}(D)}$

- $dT/dD \neq 0$ maybe
- Geologic time isn't sufficient to reach equilibrium
- Ongoing / recent charge of new fluid(s) into R
-



Any $z_i(D)$ model can be used to extrapolate beyond real (in-situ) compositional data **FOR** sensitivities.

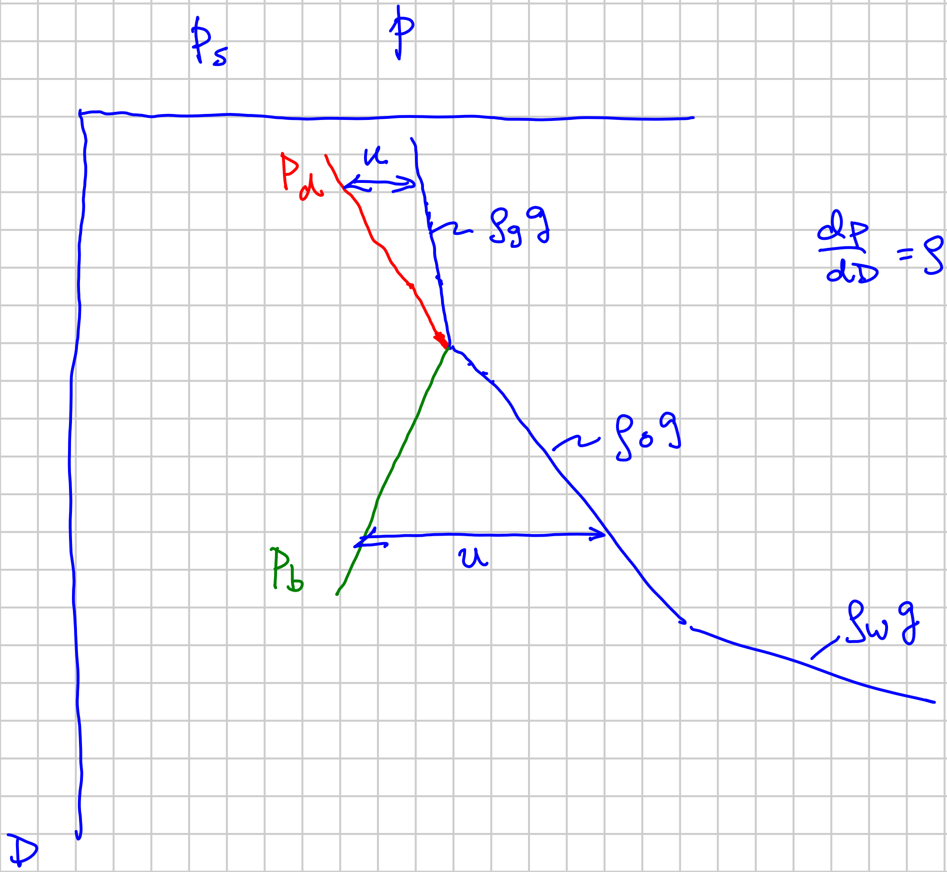
$z_{ix}(D)$ = constant

Base Case for Frac.

Isothermal CGE

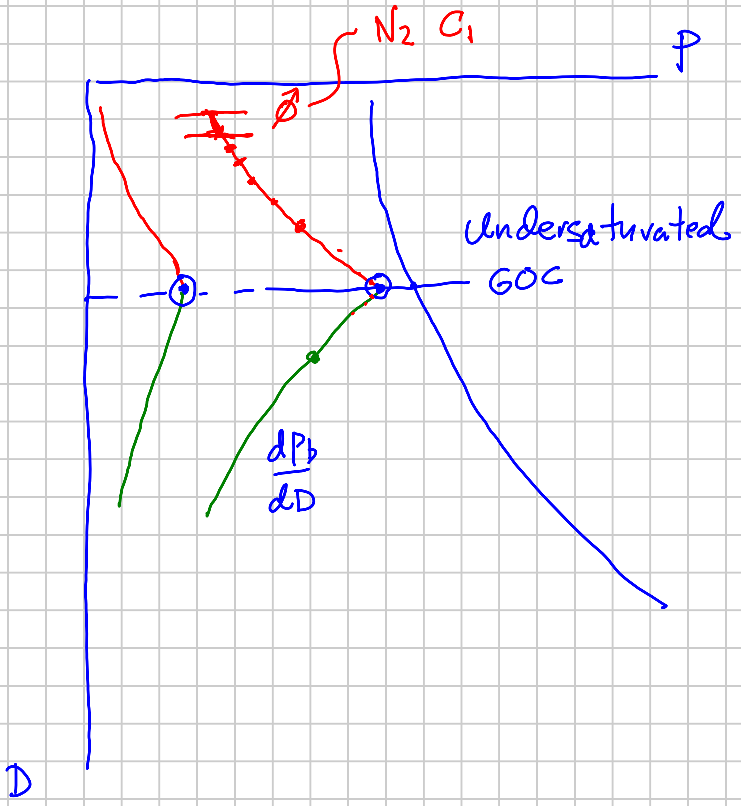
$z_i(D)$ may vary.

Isothermal CGE



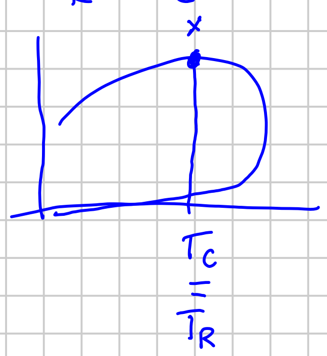
$$\frac{dp}{dD} = \rho g$$

Smørbukk South

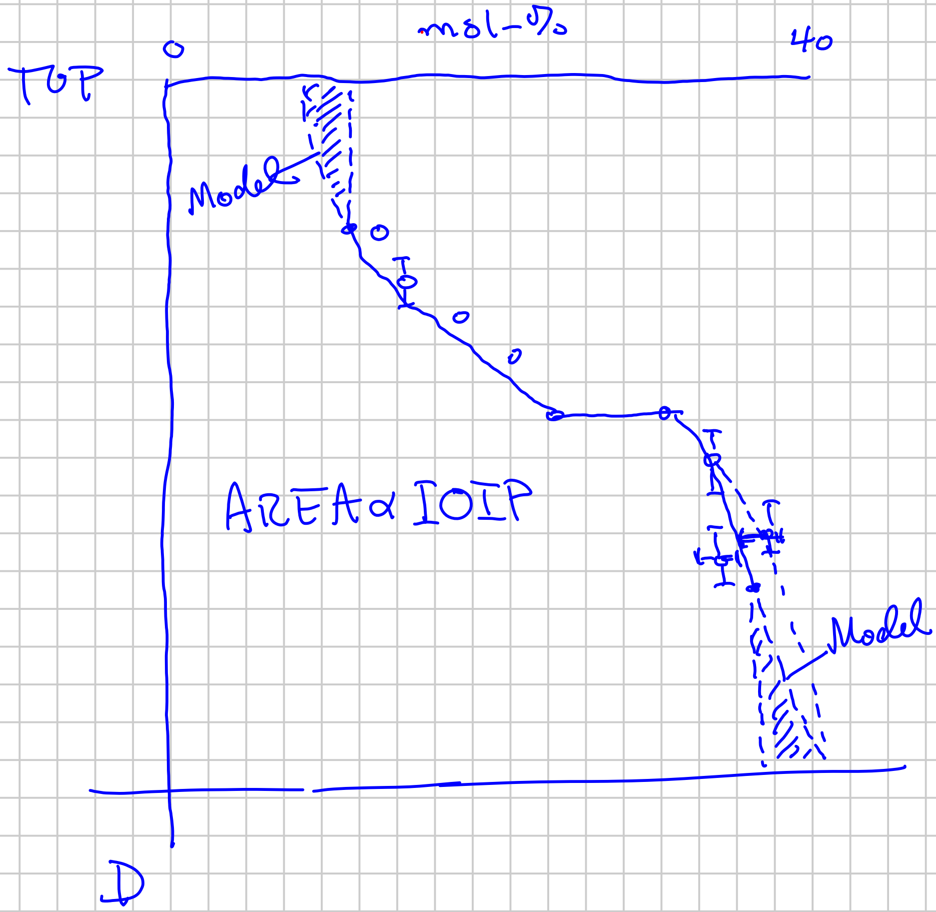


$\odot$ z_i @ GOC:

$T_R = T_c$



z_{5+} z_{6+}



o MDT

DST or early prod. data