WEDNESDAY REVIEW

PVT Lab Tests (Conventional)

		CCE	SEP	DLE	CVD
⊙ Lab Procedures	*				
(•) Measured data					
⊙ Reported quantities	*				
• Uncertainties	*				
(•) QC	*				
(•) Applications (direct)					

Ch. 6

⊙ Covered
(•) Partly Covered
• Not discussed

CCE : Constant Composition (Mass)
SEP : Multi-Stage Separator Test
DLE : Differential Liberation
CVD : Constant Volume Depletion

* VERY important to tuning EOS model

* EOS MODEL TUNING
  - STRATEGY
  - MECHANICS
  - EXAMPLE (CLOIW)

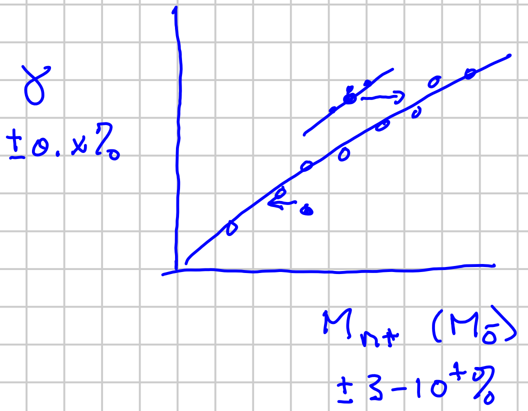
* VISCOSITY MODEL TUNING

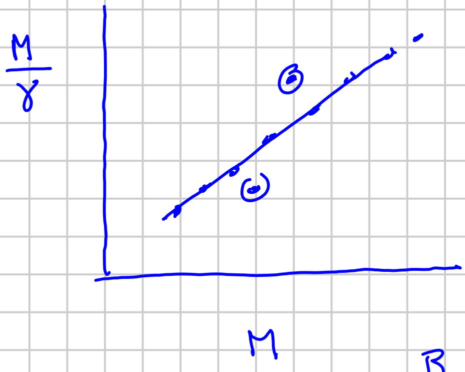
* BLACK-OIL PVT MODEL
  - What
  - How to Build from EOS
  - Challenges & Problems
  - When good enough, when not

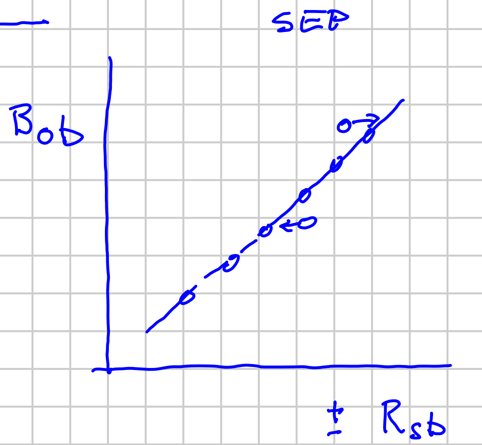
EOS MODEL TUNING STRATEGY

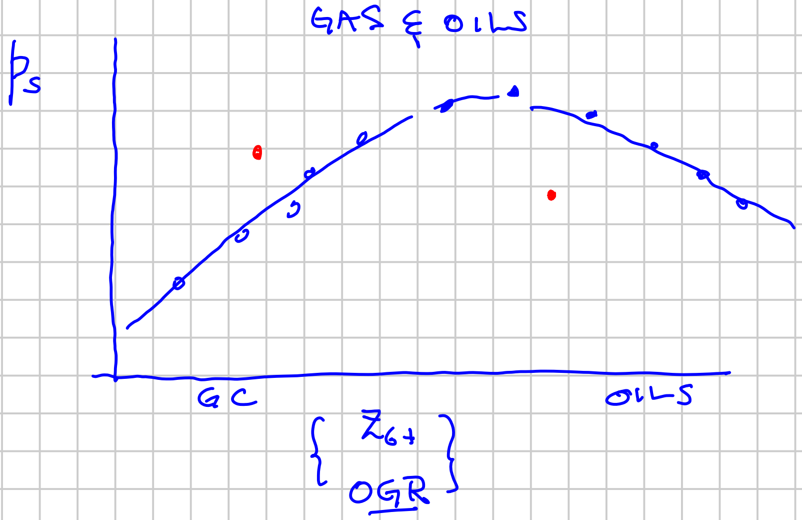
* Compositional Data QC (Excel)
* —— " —— Enter to PVT Program (QC)
* PVT Data QC (Excel) -
  - Individual Samples : mat. balance, plotting
  - Trend plots (define trends, outliers) Multiple PVT Studies

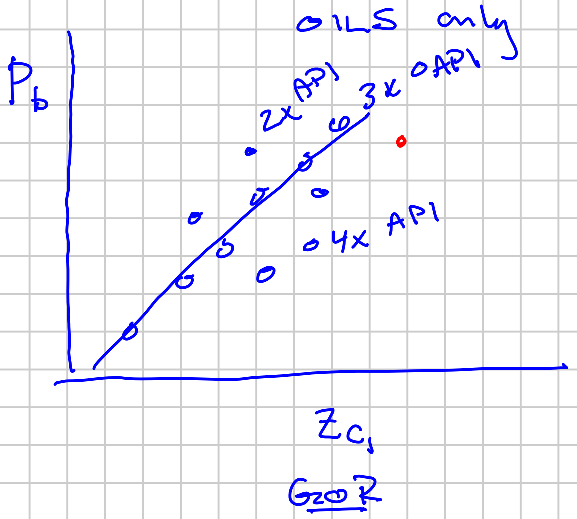
TBP & $\bar{\sigma}$ C_{n+}

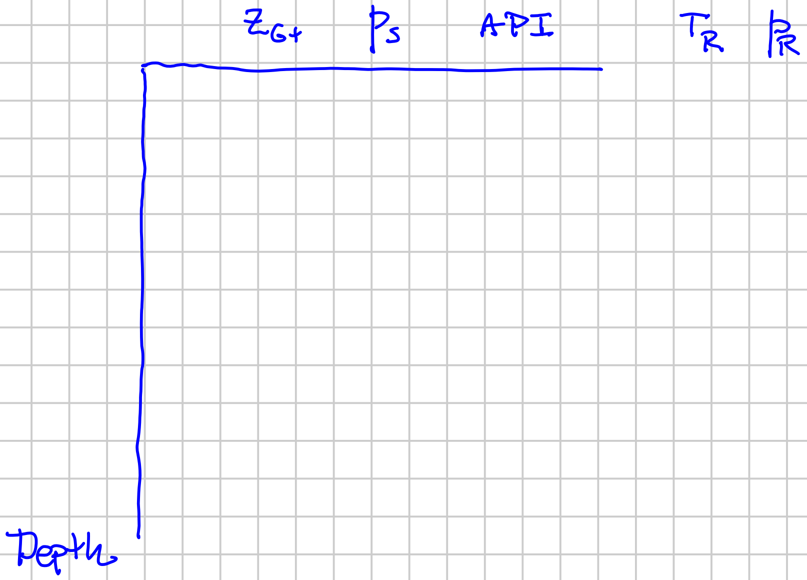












* PVT Data Entry to PVT Program $\underline{\underline{(QC)}}$

└ Simple plotting

* Prediction EOS Calculation (using Default Characterization)

- Expect "Reasonable" match w/ PVT data

⇒ • p_s ± 2-15% $= \underbrace{a+b}\ln(i)$

⇒ • ρ_o ± 1-3%
Z_g $\Big\}$ >2-3% $\left(\gamma_i = f(M_i, \underline{\underline{C_f}}) \right)$

(Fix this $\underline{\text{now}}$)

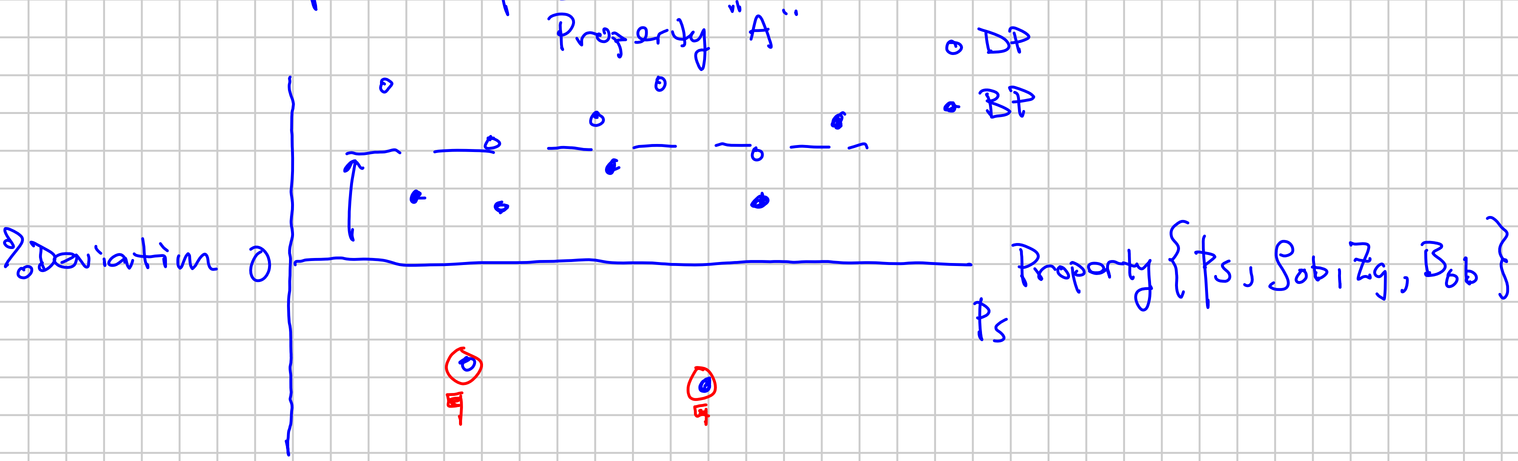
⇒ • SEP: B_{ob} (oils) GOR/OGR ± 2-5 (B_o) ± 5-1x % GOR

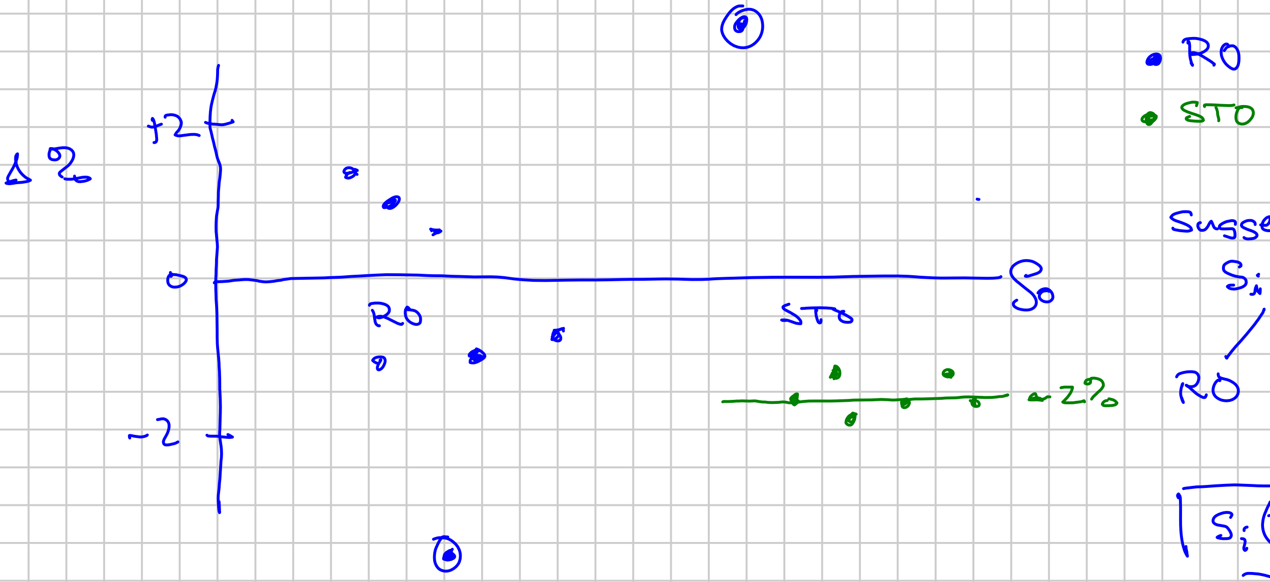
• V_{ro}^{CVD} $\overset{DLE}{B_{od}}$ ~ V_o oil shrinkage
G.C. Volatile oils

- $y_{G+}^{CVD}(p)$! Gas Cond.

* Assessment of the Mismatch

- Multiple Samples





Suggest

S_i C_{7+}

RO STO

$\boxed{S_i(T):}$

PVTsim

NOT ECL300

$c_i = a_0 + a_1 T$

$s_i = \frac{c_i}{b_i}$

$c_i(60°F)$ 22

$c_i(280°F)$ 22

$b_i = \Omega_b \frac{R^2 T_c^2}{P_c^2}$

cc/g-mole

* Act on the Assessment (P_s, ρ_o become unbiased)

- ρ_o biased : fix the $\gamma_i(M_i, C_f)$

- p_s biased : Change (manually) $k_{\underbrace{C_1-C_{7+}}}$ default

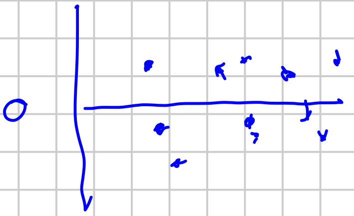
$\downarrow \uparrow$

BIP

HC-HC

$\boxed{\downarrow}$

unbiased



$C_1-C_7 \quad 0.02$

$C_1-C_{30+} \quad 0.08$

} PR

Calsep | PVTsim

Dewpoint

} $k^{SRK}_{HC-HC} = 0$ default

$$\begin{cases} p_d = f\left(K_{n+}\right) \\ p_b = f\left(K_{C_1}\right) \end{cases}$$

$\updownarrow$

$\underbrace{k_{C_1-C_{7+}}}_{| \quad | < 0.2} \neq 0$

$K_{C_1} \uparrow \quad p_b \uparrow$

$K_{C_{7+}} \downarrow \quad p_d \uparrow$

Prausnitz-Chueh

$$k_{ij} = A\left[1-\left(\frac{2v_{ci}^{1/6}v_{cj}^{1/6}}{v_{ci}^{1/3}+v_{cj}^{1/3}}\right)^B\right], \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (5.79)$$

$\updownarrow$

$A \sim 0.18 \quad B = 6$

$\sim$

$A = 1 \quad B = 1$

$\updownarrow$

$v_{ci} = \frac{RT_{ci}Z_{ci}}{P_{ci}}$ 0.000x 0.00x → 0.0x

Many PVT Reported Quantities are Relative to $\underbrace{p_s}_{\text{Refrence State}}$

* OK slightly modified default EOS ρ_o ✓ p_s unbiased

* Choosing Variables to Tune With (Pool of Variables)

(1) – C_{7+} (Table 1) Properties $\{T_{ci} \quad p_{ci} \quad \omega_i\} = \Theta_i$

- More uncertainty in $\Theta_i \updownarrow$ as SCN increases

NOT s_i : $s_i \Leftrightarrow \underbrace{\gamma_i (M_i, C_f)}_{\text{unchanged}}$

- Best if changes were "similar" for all the C_{7+} but more change for heavier

(2) – C_{N+} (25+ 30+ 35+) could be quite different in chemical makeup and most uncertain $\Theta_{N+} \updownarrow$

(3) – k_{ij} all HC–HCs

$\Rightarrow$ {
- $C_1 - C_{7+}$ biggest effect on p_s
- Entire matrix Chueh-Prausnitz (single variable) "A"

(!) • $C_{7+} - C_{7+}$ huge impact on high-p $K_i(p)$ "nose" impact retrograde condensation, CP, near-critical

$V_{(1)-(3)}$ 10s – 100s will impact all samples in a similar, consistent way | Max. 5-10 EOS Variables

Sample-Dependent Variables $\Rightarrow$ mol-% change in
(1) C_1 | C_{7+} $\lesssim$ 2 mol-%
(2) should ~ all PVT calculations

– M_{n+} : used to convert $w_i \to z_i$

$$z_i = \frac{w_i / M_i}{\left(\sum_{j=1}^{n-1} w_j / M_j\right) + \frac{w_{n+}}{M_{n+}}}$$

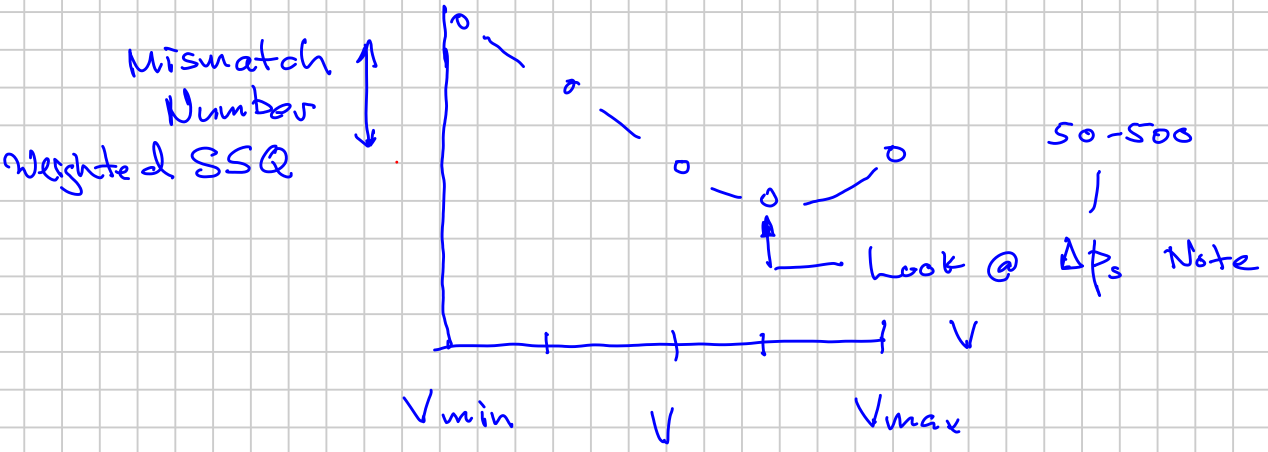
$\leftarrow$ Could be very different sample to sample (Which PVT programs allow) PVTx | PhazeComp

– w_{N+} z_{N+} always uncertain

– Flash-GC-Recomb "GOR"

- * Select to Weigh some data ↑ ↓
  - Importance of data w/ how many of that kind of data
  - Experimental uncertainty $\Delta p_s \pm \underline{1\text{–}5 \text{ psi}}$

- * Start systematic Tuning
  - Try '1D' (single variable) sensitivities



−5%	+5%	T_c P_c ω $C_7 - C_{N-1}$
−10%	+10%	Θ_i C_{N+}
−0.1	0.2	$k_{C_1-C_{7+}}$

- Adjust mouts on key-data weight factors (p_s)

- Multi-variable automated regressions
  - Trying different combinations of V_j
  - Adjusting a bit some weight factors
  - ⋮ Keep a Journal
  - Quit

Look at all calculations Plots & Tables each case

~ days
~ weeks

Residual Weighting Within PhazeComp

Aaron A. Zick, Ph.D.
Zick Technologies

January 22, 2007

$$\chi^2 = \sum_{i=1}^{N} (\overset{\text{you control}}{w_i} r_i)^2,$$

w_i = weight factor

r_i = residual

$$\text{min} \; \underset{\text{RMS}}{\boxed{\bar{r}}} = \sqrt{\frac{\chi^2}{\sum_{i=1}^{N} w_i^2}},$$

%

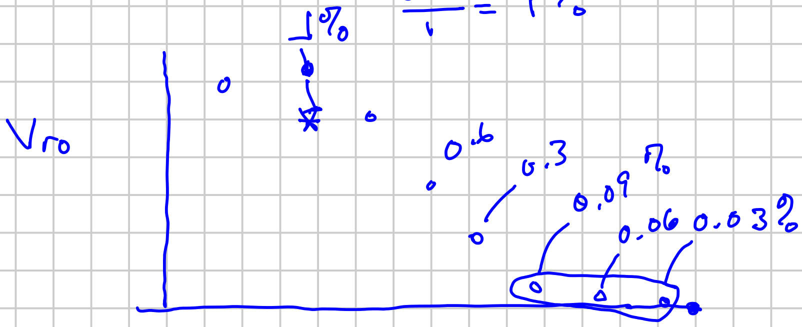
1-3%

Reference : $r_i = \Delta_i$ use $y^r = y^e$

$$r_i = 100(\overset{\text{EOS}}{y_i^c} - \overset{\text{LAB}}{y_i^e})/y_i^r,$$

= max of data of a given type in a given experiment

$\frac{0.01}{1} = 1\%$



$\frac{0.01}{0.03} = 0.33$

33%

min WSSQ by changing $\boxed{V_j}$

EOS

Sample-Specific

① Which data are poorly predicted ?

x - $R_{sd,b}$

x - $B_{od}(p)$

Plot $R_{sd}(p)$

$B_{od}(p)$

$B_{od}(R_{sd})$

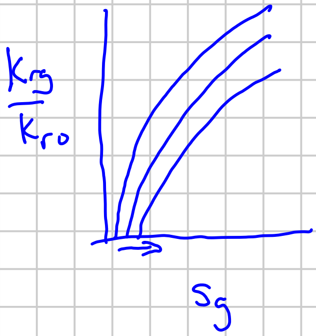
② Which data are most important ?

- Depletion SGD : Low vs high RF_o ?

$\underline{V_o(p)\quad \Delta R_s,}$

$B_{od}(p)$: $R_{sd}(p)$

$\frac{k_{rg}}{k_{ro}}(\underline{S_g})$



③ Any missing data ?

$$a = \Omega_a \frac{R^2 T_c^2}{p_c} \cdot \alpha$$

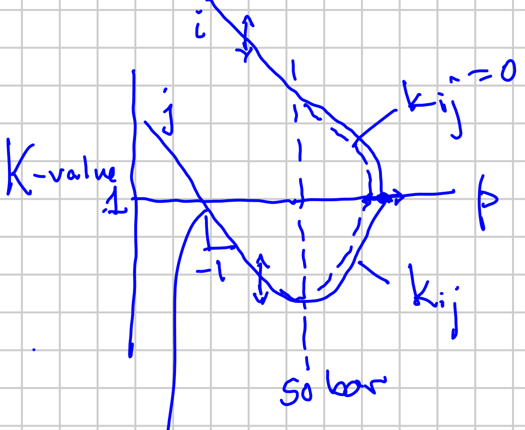
$$\alpha_{RK} = 1/\sqrt{T_r}$$

$$\alpha_{SRK} = f(T_r, \omega)$$

BIPs $\boxed{k_{ij}}$ Are correction terms

① Mainly change $\underline{K_i}$ and $\underline{K_j}$ in the $\underline{p \gtrsim 50 \text{ bar}}$

②



$\underline{\text{All}}$ components K-values are affected also, because joined @ p_K

$$K_i = \frac{p_{vi}(T)}{p}$$

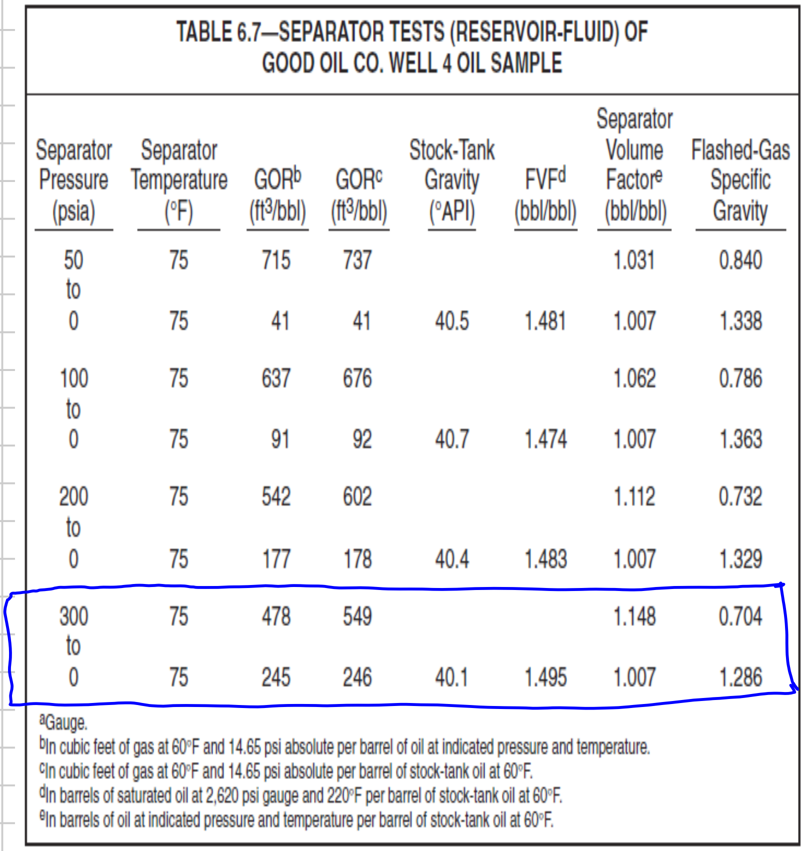
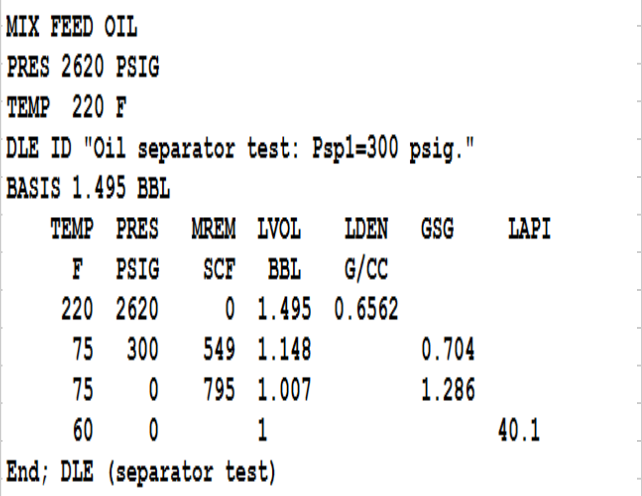


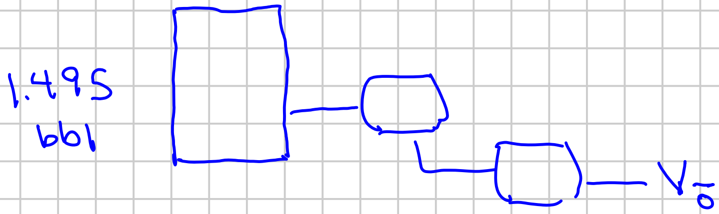
TABLE 6.7—SEPARATOR TESTS (RESERVOIR-FLUID) OF GOOD OIL CO. WELL 4 OIL SAMPLE

Separator Pressure (psia)	Separator Temperature (°F)	GOR[b] (ft³/bbl)	GOR[c] (ft³/bbl)	Stock-Tank Gravity (°API)	FVF[d] (bbl/bbl)	Separator Volume Factor[e] (bbl/bbl)	Flashed-Gas Specific Gravity
50	75	715	737			1.031	0.840
to							
0	75	41	41	40.5	1.481	1.007	1.338
100	75	637	676			1.062	0.786
to							
0	75	91	92	40.7	1.474	1.007	1.363
200	75	542	602			1.112	0.732
to							
0	75	177	178	40.4	1.483	1.007	1.329
300	75	478	549			1.148	0.704
to							
0	75	245	246	40.1	1.495	1.007	1.286

[a] Gauge.
[b] In cubic feet of gas at 60°F and 14.65 psi absolute per barrel of oil at indicated pressure and temperature.
[c] In cubic feet of gas at 60°F and 14.65 psi absolute per barrel of stock-tank oil at 60°F.
[d] In barrels of saturated oil at 2,620 psi gauge and 220°F per barrel of stock-tank oil at 60°F.
[e] In barrels of oil at indicated pressure and temperature per barrel of stock-tank oil at 60°F.



```
MIX FEED OIL
PRES 2620 PSIG
TEMP  220 F
DLE ID "Oil separator test: Psp1=300 psig."
BASIS 1.495 BBL
    TEMP  PRES   MREM  LVOL    LDEN   GSG     LAPI
      F   PSIG    SCF   BBL    G/CC
    220  2620      0  1.495  0.6562
     75   300    549  1.148          0.704
     75     0    795  1.007          1.286
     60     0          1                     40.1
End; DLE (separator test)
```



$$B_{ob}^{EOS} = \frac{1.495}{0.9981} \quad vs$$

$$B_{ob}^{Lab} = \frac{1.495}{1}$$

Pool of Variables:

* $k_{C_1-C_{7+}}$ or k_{HC-HC} [1]
* C_{30+} T_{ci} P_{ci} ω_i [3]
* M_{7+} $(\omega_i \to z_i)$ [1]
* z_{30+} [1]
* GOR_{FGCR} [1]

$$\left.\begin{array}{l} M_{7+} \; (\omega_i \to z_i) \; [1] \\ z_{30+} \; [1] \\ GOR_{FGCR} \; [1] \end{array}\right\} \text{Composition Variables}$$

$\{$ * C_{7-29} T_{ci} P_{ci} ω_i [3] $\}$

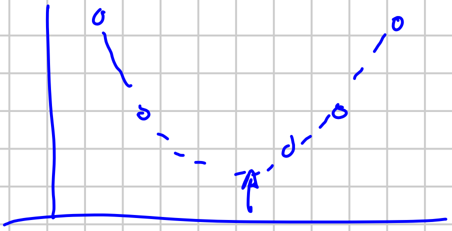
Ph2: Introduce a Variable

VARIABLE v-name v-start { v-min v-max }

Apply the variable v-name

MULTIPLY
DIVIDE
INCREASE
DECREASE

REPLACE



BIPS-C1-C7+-MULTIPLIER	RMS %	P_b psig [2620] Lab
0	11.62	2241
0.5	7.585	2414
1	5.075	2615
> 1.01		2620
1.5	8.332	2852
2	15.42	3139

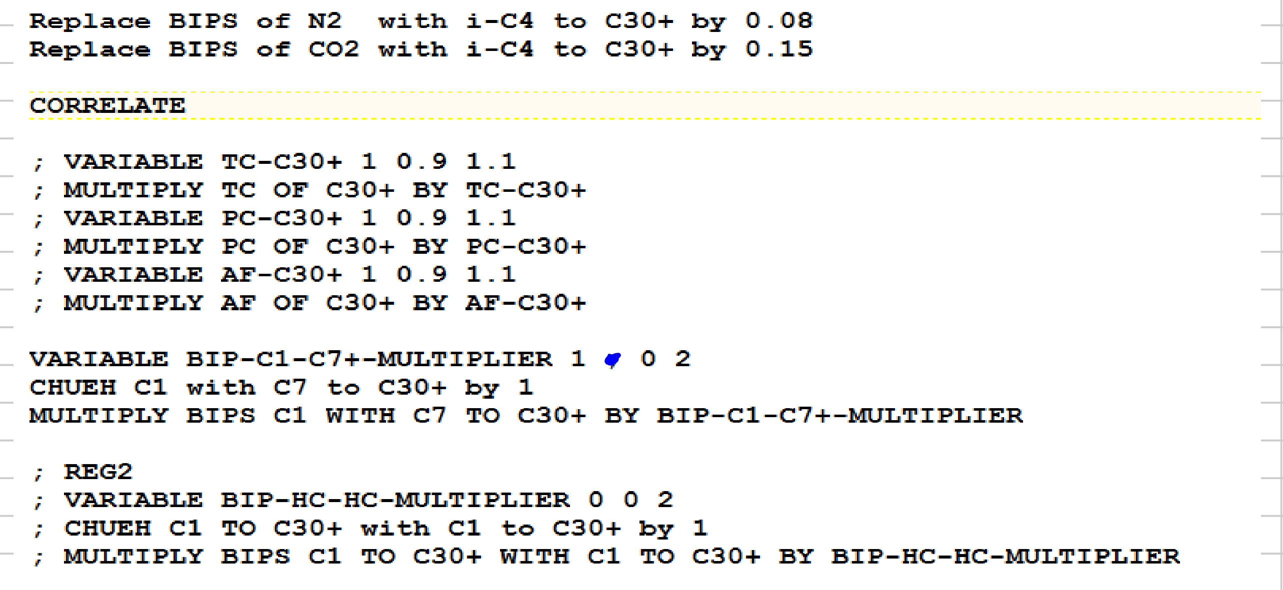
Next Try: D = default

Lab [2620]

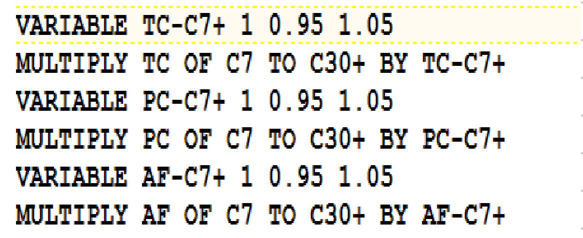
							"Flash-GC-Recomb"	Final	
	$k_{C_1-C_7}$	k_{AC-HC}	T_{c30+}	P_{c30+}	ω_{30+}	M_{7+}	GOR	RMS %	P_b psig
1	(1.01)					1 Variable		5.075	2620 [767]
2		(0.866)						5.864	2591
3	1	–	(1)					5.075	2620
4	1	–	D	(1)				5.075	2620
5	1	–	D	D	(1)			5.075	2620
6	(1.67)		(1.036)			2 Variable		5.03	2620
7	(1.41)		D	(0.9)				5.04	2620
8	(1)		D	D	(1.004)			5.075	2620

9	(1.55)	(1)	(0.9)	(1)	4-variable	5.036	2618
10	(2)	(1.041)	(1.05)	(1)	w/ C_{7+} not C_{30+}	4.405	2612 749

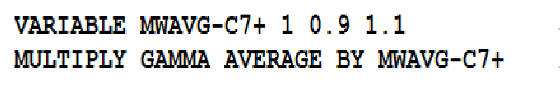
[697]



```
Replace BIPS of N2  with i-C4 to C30+ by 0.08
Replace BIPS of CO2 with i-C4 to C30+ by 0.15

CORRELATE

; VARIABLE TC-C30+ 1 0.9 1.1
; MULTIPLY TC OF C30+ BY TC-C30+
; VARIABLE PC-C30+ 1 0.9 1.1
; MULTIPLY PC OF C30+ BY PC-C30+
; VARIABLE AF-C30+ 1 0.9 1.1
; MULTIPLY AF OF C30+ BY AF-C30+

VARIABLE BIP-C1-C7+-MULTIPLIER 1 [illegible] 0 2
CHUEH C1 with C7 to C30+ by 1
MULTIPLY BIPS C1 WITH C7 TO C30+ BY BIP-C1-C7+-MULTIPLIER

; REG2
; VARIABLE BIP-HC-HC-MULTIPLIER 0 0 2
; CHUEH C1 TO C30+ with C1 to C30+ by 1
; MULTIPLY BIPS C1 TO C30+ WITH C1 TO C30+ BY BIP-HC-HC-MULTIPLIER
```



```
VARIABLE TC-C7+ 1 0.95 1.05
MULTIPLY TC OF C7 TO C30+ BY TC-C7+
VARIABLE PC-C7+ 1 0.95 1.05
MULTIPLY PC OF C7 TO C30+ BY PC-C7+
VARIABLE AF-C7+ 1 0.95 1.05
MULTIPLY AF OF C7 TO C30+ BY AF-C7+
```



```
VARIABLE MWAVG-C7+ 1 0.9 1.1
MULTIPLY GAMMA AVERAGE BY MWAVG-C7+
```

$$\boxed{M_{7+} \times 0.9}$$

$K_{ij} \times 1.29$

C_f $\underline{0.296}$

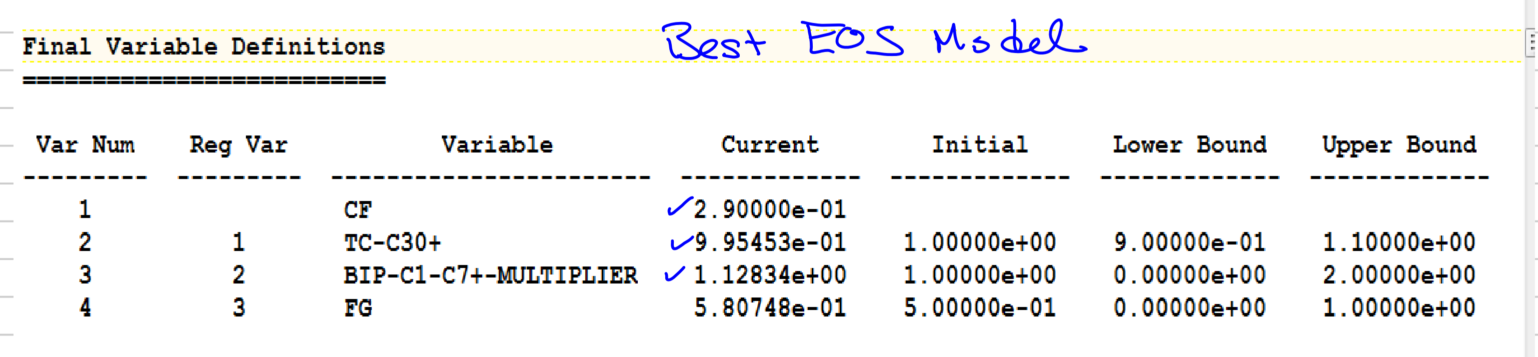
WT API 10

RMS $\underline{3.794}$ $P_b = 2618$ ✓

$P=159$ $R_{sol} = \underline{762}$ $B_{od} = \underline{1.1965}$

$\boxed{\text{FGCR GOR}}$ EQV EQL

$$z_i = \underbrace{f_g\ y_i}_{\text{FLASHED-GAS}} + \underbrace{(1-f_g)}\, x_i$$



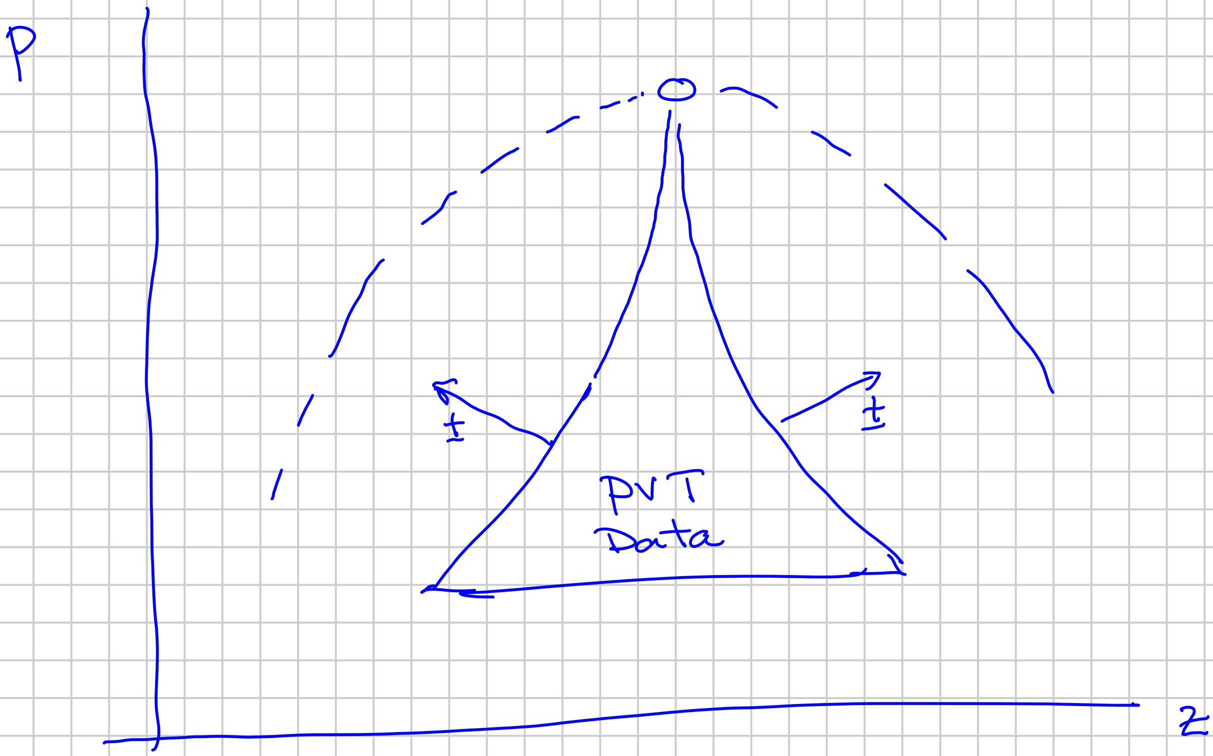
Best EOS Model

```
Final Variable Definitions
============================

 Var Num     Reg Var          Variable              Current         Initial       Lower Bound     Upper Bound
---------   ---------   ------------------------  -------------  -------------  -------------  -------------
    1                    CF                       ✓2.90000e-01
    2           1        TC-C30+                  ✓9.95453e-01   1.00000e+00    9.00000e-01    1.10000e+00
    3           2        BIP-C1-C7+-MULTIPLIER    ✓1.12834e+00   1.00000e+00    0.00000e+00    2.00000e+00
    4           3        FG                        5.80748e-01   5.00000e-01    0.00000e+00    1.00000e+00
```

RMS = 4.05

R_{sd} = 736 Bod = 1.21

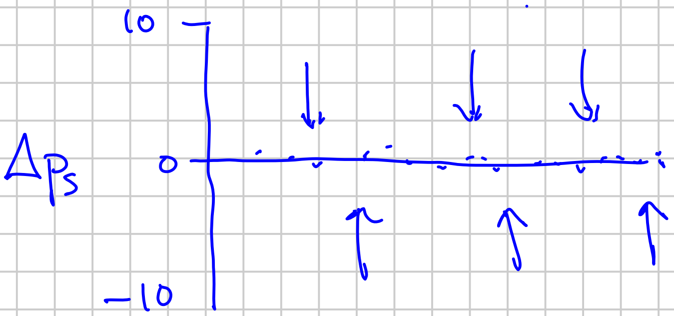
ρ_o ✓



Smaller EOS Property Changes

+

⊛ Smaller by-sample composition changes



OIL VISCOSITY MODELING

Alani-Kenedy

① LBC (Lorentz Bray Clark) "Jossi-Thodos" Pure Compounds

Oils $\boxed{v_{cC_{7+}}(M_{7+},\gamma_{7+})}$

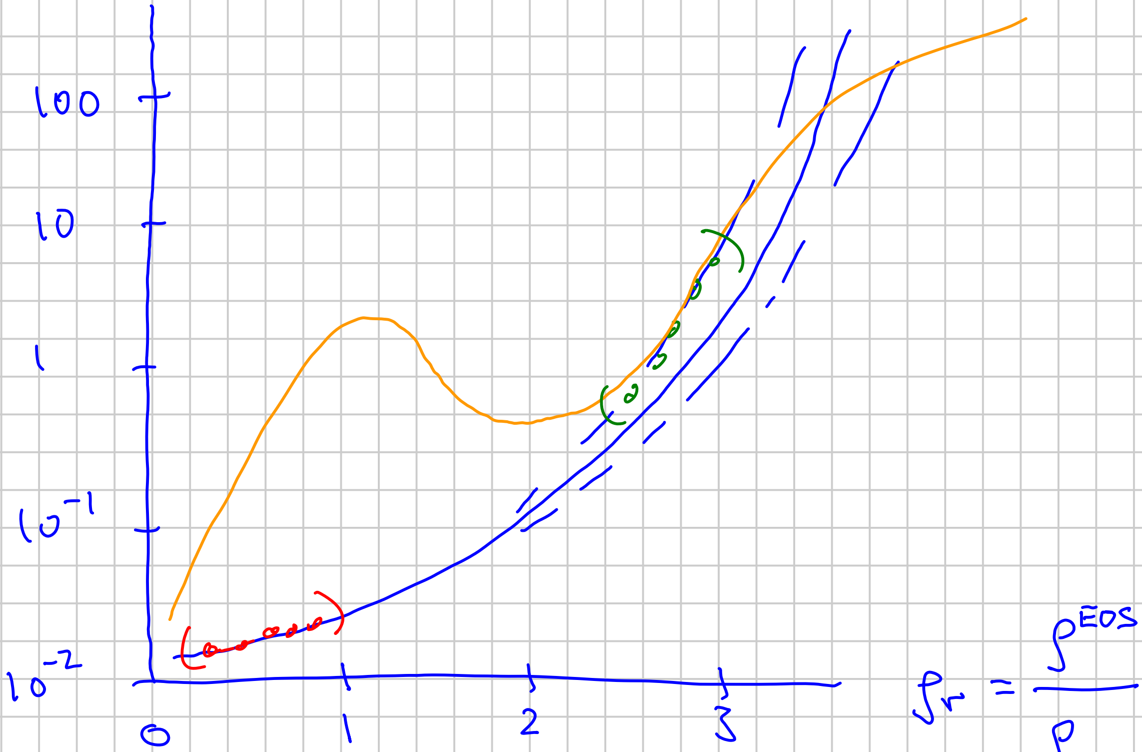
② Pedersen

- Tuning: don't know, ask Calsep

$\rho_r = \frac{\rho}{\rho_{pc}}$ $\rho_{pc} = \frac{M}{v_c}$

LBC:

$$\mu - \mu^\circ = \left[a_0 + a_1\rho_r + a_2\rho_r^2 + \underline{a_3}\rho_r^3 + \underline{a_4}\rho_r^4\right]^4$$



$\rho_r = \frac{\rho^{EOS}}{\rho_{pc}}$

Yang Fevang

A procedure

Est.

$\underline{M_i}$ $\underline{\gamma_i}$ | $\underline{\mu_{L1}}(T) = \overset{LBC}{\mu_{L1}}(T)$ Z_{ci} $\underline{v_{ci}}$

C_7 ✓

C_8 ✓

⋮ ✓

✓

✓

C_{30+} ✓

find v_c each C_{7+} fraction

$$\rho_{pc} = \frac{p_{pc}M}{RT_{pc}Z_{pc}} = \frac{M}{v_{pc}}$$

$$v_{pc} = \sum \overset{\nearrow y_i \ \uparrow x_i}{u_i} v_{ci}$$

KEY: v_{ci} C_{7+} fractions

$\mu_o^{DLE}(p)$ $\pm$ 5-20% → $v_c + \underbrace{\Delta v_c}$ | $Z_c + \underbrace{\Delta Z_c}$

$\mu_g(p)$

Change a_3 a_4

$\underbrace{\underline{M}\ \underline{T_c}\ \underline{P_c}\ \underline{\omega}}_{K_i}$ s $\overset{v_c}{Z_c}$ 5-10%

$\boxed{C_{N+}}$ → L (P) ✓ ✓

$\boxed{C_{N+}}$ → H (A) ✓ ✓

API variations

Troubles fitting <u>all</u> oil μ_o

Black-Oil PVT

optimize to minimize error in the important $\rho_g(p,T)$ $\rho_o(p,T)$

* BO Properties : $\boxed{\rho_{\bar{g}} \mid \rho_{\bar{o}}}$

OIL PHASE

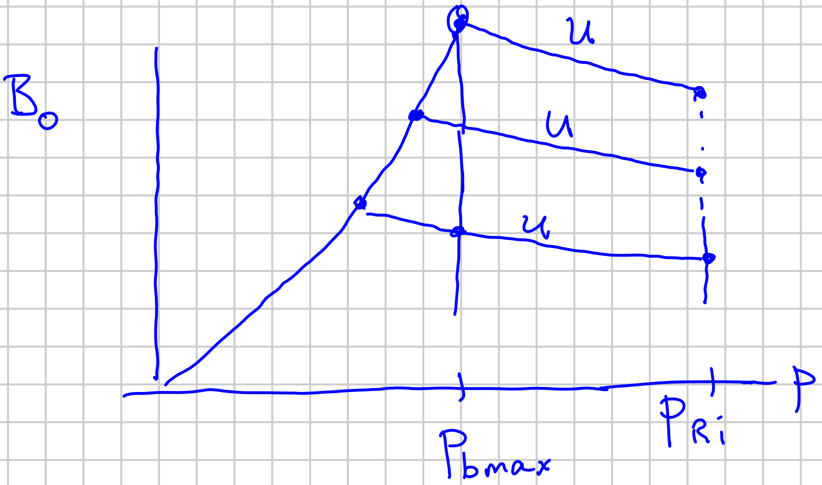
$B_o(p)$ $R_s(p)$ $\mu_o(p)$

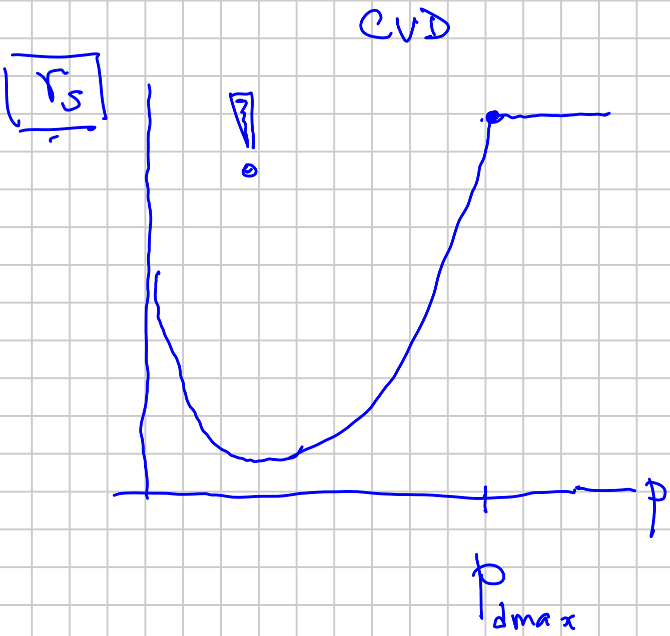
$S \neq U @p$

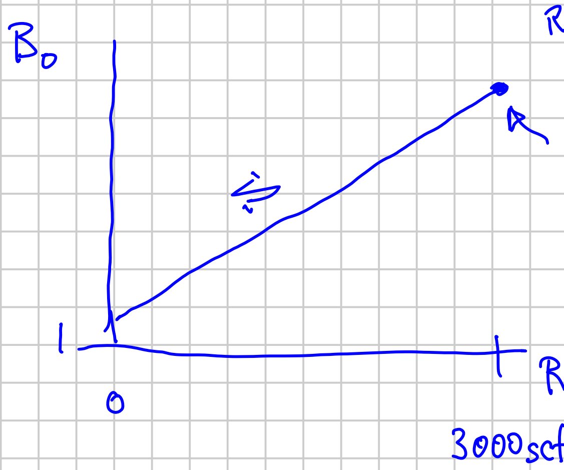
GAS PHASE

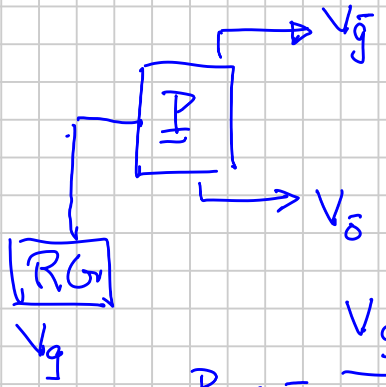
$\underbrace{B_{gd}(p)}_{✓}$ $\underbrace{r_s(p)}_{R_v}$ $\underbrace{\mu_g(p)}$

$S \sim U$ @p









$$B_{gd} \equiv \frac{V_g(p,T)}{V_{\bar{g}}}$$

$$\boxed{B_{gw} = \frac{p_{sc}}{T_{sc}} \cdot \frac{T_R Z_g^{sk}}{p}}$$

$$\rho_g(p,T) = \frac{\rho_{\bar{g}g} + r_s(p,T)\,\rho_{\bar{o}g}}{B_{gd}(p,T)}$$

$$\rho_o(p,T) = \frac{\rho_{\bar{o}o} + R_s(p,T)\,\rho_{\bar{g}o}}{B_o(p,T)}$$

$$B_{gd} = B_{gw} \frac{1}{(1-y_{wt})}$$

$$C \cdot \frac{y_{wt}}{1-y_{wt}} = r_s$$

How to Build BO PVT from an EOS (Ch. 7)

Required Input:

1. EOS (EOS-R | EOS-S | $s_i(T)$)

2. z_{BOi} "pick the sample withe the highest p_s" **SPE 63087**

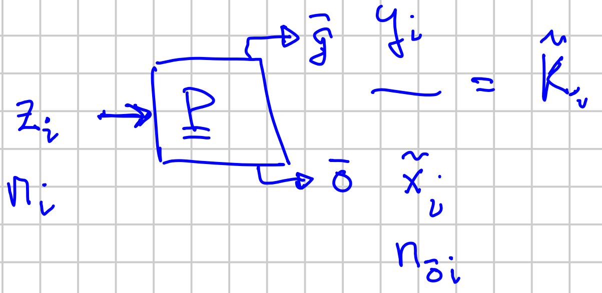
   GOC (S|U) @ GOC if ands & buts

3. Surface Process ($\to \bar{g}$ $\bar{o}$)

✓ – EOS-based

– $\tilde{K}_i$ (Statoil)

– $RF_{\bar{o}i}$ (z_{N+})



$$\underbrace{RF_{\bar{o}i} = GP_i = \frac{n_{oi}}{n_i}}$$

"GP Table" $= f(z_{N+})$

4. Method of Depletion (p_{smax} of $z_{BOi} \to$ lower p's)

   $\underbrace{\text{CCE | CVD}}_{✓}$ | DLE

5. Saturated List of $p < p_{smax}$

6. Undersaturated List of $p > p_{smax}$

{7.} Method saturated table extrapolation

- Gas Injected
-
-

$p_s > p_s(z_{BOi})$

SPE 63087

$\rho_{\bar{9}}$ The surface process of Z_{Boi}

$\rho_{\bar{0}}$