Note Title 5/11/2016

TUESDAY REVIEW

* EOS (Cubic)
  - SRK | PR(77|79)
  - PVT Calcs (Gas | Oil | Critical & Undefined) = $f(p, T, z_i)$
    - Phase Amounts | Densities | Compositions
    - Saturation Pressure | Flash | Stability VLE,

Ch.4 - $\mu_{iV} = \mu_{iL}$ | $\mu_i(EOS, p, T, z_i) = RT \ln f_i$ (fugacity)

- EOS Definition Ω_{ai} Ω_{bi}

EOS MODEL
- Table 1 - M_i T_{ci} p_{ci} ω_i S_i {C_{ai} C_{bi}}
- Table 2 - k_{ij} BIPs | $k_{ij} = k_{ji}$, $k_{ii} = 0$, $k_{non\text{-}HC/HC} \sim 0.1$
  - EOSxx (Tuned Model | Process Model) xx: 15-40+
  - EOSx (Reservoir x<10, often 6-8)

- Molar Composition (or $m_i^{w_i} \rightarrow M_i \rightarrow z_i$)
  - Same component slate as EOS model
  - Map of z_i components to EOS model components

- EOS (Thermodynamic) Validation
  - K_i @ p_s monotonicity of HCs $f(T_{bi}^{EOS}, M_i)$
  - $K_i(p)$ not crossing for HCs
  - $\gamma_i^{EOS} \sim \gamma_i(M_i)$ data or correlation trend
  - 3-phase equilibrium test = $f(p, T, z_i)$

* C_{7+} Characterization (Part B)

- Estimate component EOS properties Table 1 – T_{ci} p_{ci} ω_i S_i

① $\gamma_i(M_i, C_f)$: tuned to γ_{n+} or ρ_o data/input

② (a) $T_{bi}(M_i, \gamma_i)$ correlation

T_{ci} & p_{ci} $= f(T_{bi}, \gamma_i)$ correlation } PVTi PVTp Prop

$\omega_i = f(T_{ci}, p_{ci}, T_{bi})$ correlation

or

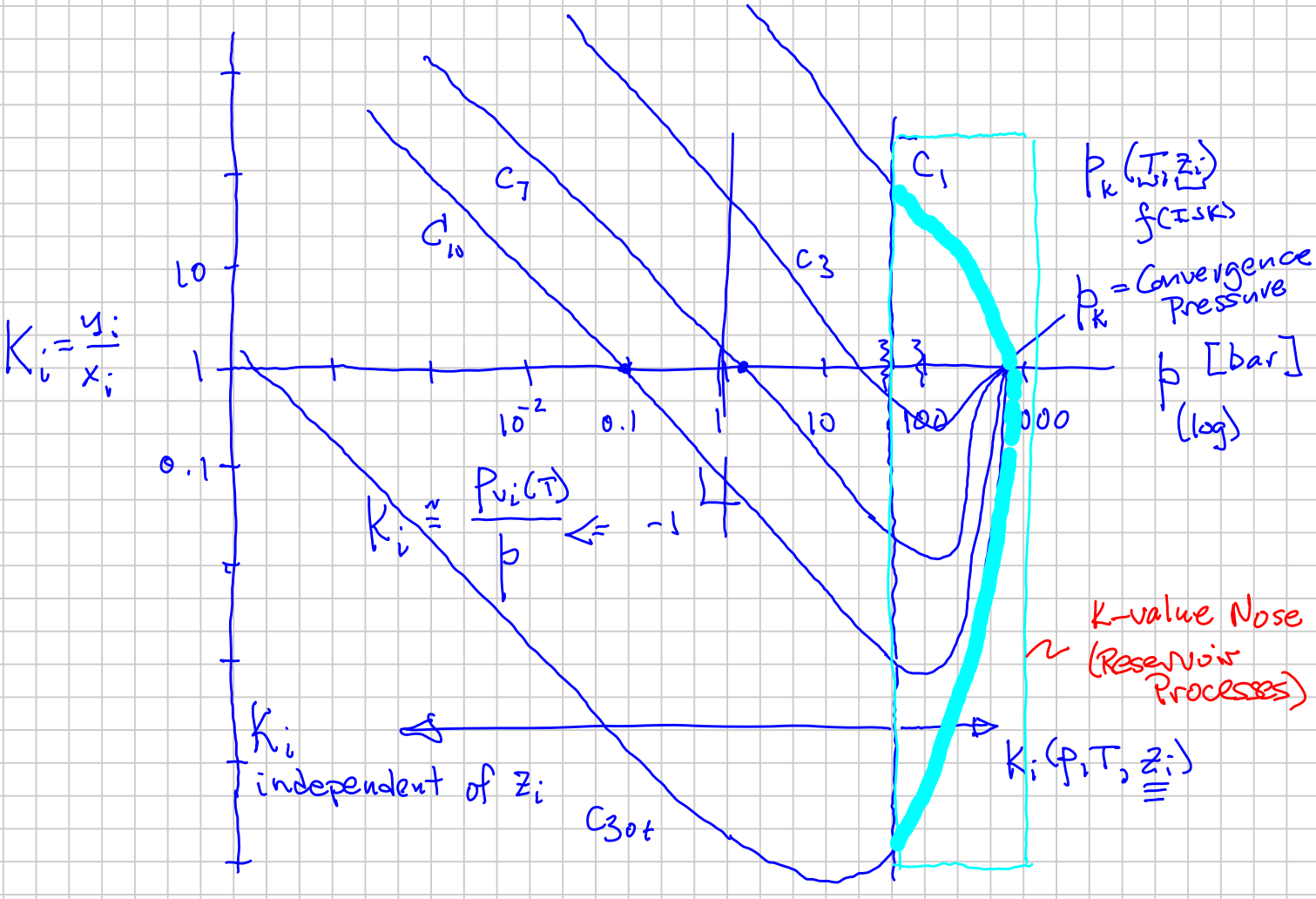
ω_i so that $T_{bi}^{EOS} = T_{bi}(M_i, \gamma_i)$ } PVTx Phaze Comp

(b) PVTsim

SRK T_{ci}, p_{ci}, m_i $= f(M_i, \gamma_i)$ Calsep-Built | $\omega_i = f(m_{i..}, EOS)$

③ S_i so that $\gamma_i^{EOS} = \gamma_i(M_i, C_f)$

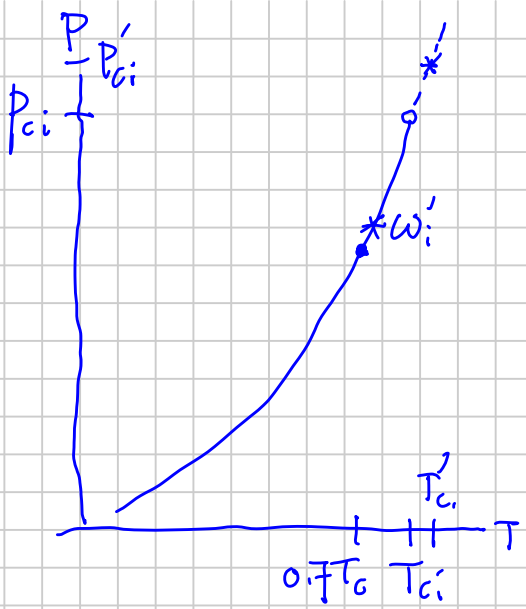
- PVTsim (<2014) S_i was not updated during tuning regression



$$p_{v_i}^{EOS}(T) \approx f(T_{c_i}, p_{c_i}, \omega_i)$$

ω_i : $\Rightarrow$ p_v @ $T = 0.7 \cdot T_c$

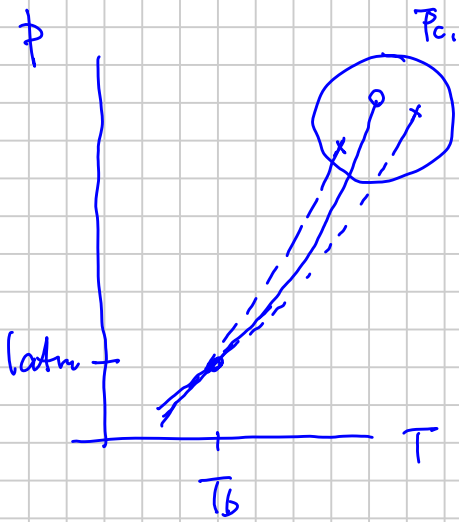
$$\omega_i \equiv -1 - \log_{10}\left(\frac{p_v @ 0.7T_c}{p_c}\right)$$



high-p K_i (Reservoir Processes)

Nose Shape & p_k : $f(C_{7+}, C_{N+}, \underline{T_{c_i}, p_{c_i}, \omega_i}, \underline{\underline{k_{ij}}})$

Also impact low-p K_i: $p_{v_i}(T)$



PVTx PhazeComp

Have T_{b_i} reliable (TBP) for C_{7+} then used to maintain during tuning

PVT Lab Tests (Conventional)

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

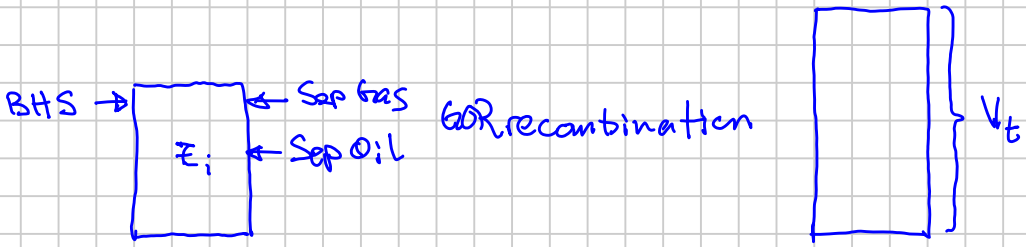
Ch. 6

⊙ 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

CCE Test

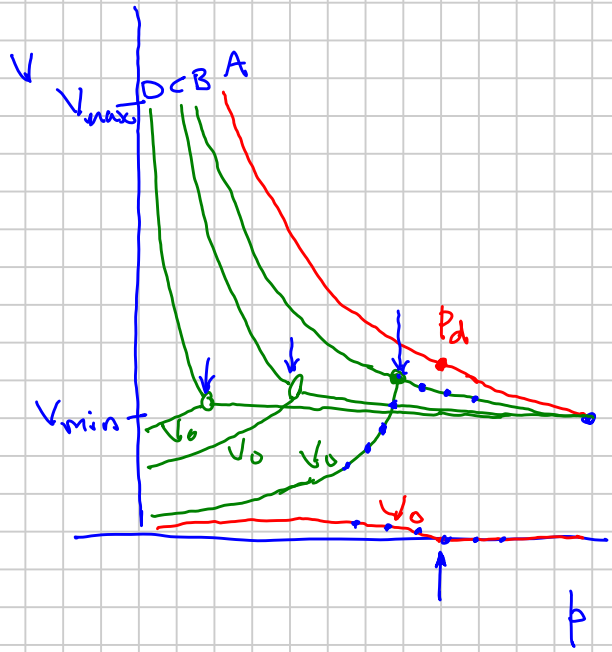


$T = T_R \sim p_{R_i}^+ = p_1$ $\qquad p_2$

$$Z_g = \frac{pV}{nRT}$$

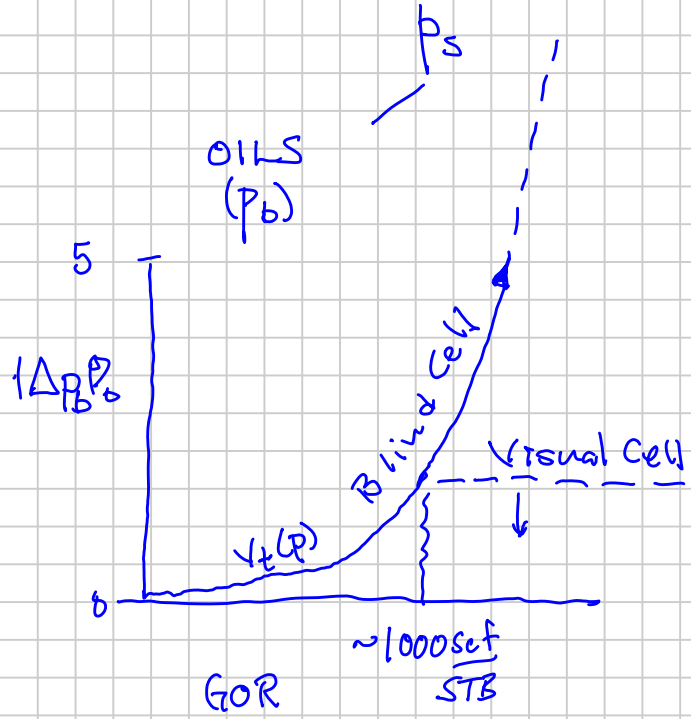
Know initially: z_i, $\boxed{m}$, $\boxed{n}$, V @ (T_R, p)
All Cells Visual PVT Cell

p	V_t	$S_o = \frac{n}{V_t}$	Z_g	V_o	
$p_{R_i}^+ \sim p_{max}$	V_{min}				Single Phase
10-20 $\boxed{p_s}$					
					Two Phase
p_{min}	$\sim 4 \cdot V_{min}$				



Accuracy: S_i, Z_g $\pm$ 1-2 % (expect) QC gas: SK $Z(T_r, P_r)$

Z_g^{SK} vs $Z_{g\,Lab}$ $\approx$ 3%



GASES
(p_d)

(1 - 5%) → (10% →)

Most Liquid Dropout "Tail"

V_o = f(PVTcell, V_o)

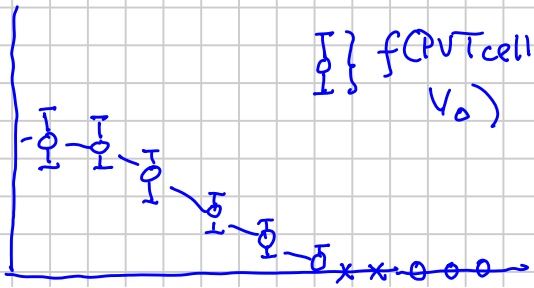


TABLE 6.9—CCE DATA (RESERVOIR-FLUID) FOR GOOD OIL CO. WELL 4 OIL SAMPLE

Saturation (bubblepoint) pressure*, psig	2,620
Specific volume at saturation pressure*, ft³/lbm	0.02441
Thermal expansion of undersaturated oil at 5,000 psi = V at 220°F/V at 76°F	1.08790
Compressibility of saturated oil at reservoir temperature	
From 5,000 to 4,000 psi, vol/vol-psi	13.48×10^{-6}
From 4,000 to 3,000 psi, vol/vol-psi	15.88×10^{-6}
From 3,000 to 2,620 psi, vol/vol-psi	18.75×10^{-6}

Pressure/Volume Relations*

Pressure (psig)	Relative volume (L)†	Y function‡
5,000	0.9639	
4,500	0.9703	
4,000	0.9771	
3,500	0.9846	
3,000	0.9929	
2,900	0.9946	
2,800	0.9964	
2,700	0.9983	
2,620**	1.0000	
2,605	1.0022	2.574
2,591	1.0041	2.688
2,516	1.0154	2.673
2,401	1.0350	2.593
2,253	1.0645	2.510
2,090	1.1040	2.422
1,897	1.1633	2.316
1,698	1.2426	2.219
1,477	1.3618	2.118
1,292	1.5012	2.028
1,040	1.7802	1.920
830	2.1623	1.823
640	2.7513	1.727
472	3.7226	1.621

* At 220°F.
** Saturation pressure.
1 Relative volume = V/V_{sat} in barrels at indicated pressure per barrel at saturation pressure.
‡ Y function = $(p_{sat} - p)/(p_{abs})(V/V_{sat} - 1)$.

p_d

Reported Quantities:

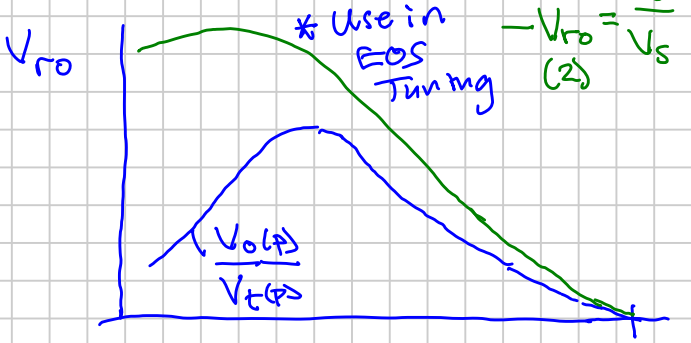
* p_s (BP | DP)
* $p > p_s$ ρ_o Z_g B_g

$$B_g = \frac{p_{sc}}{T_{sc}} \cdot \frac{T_R Z_g}{p}$$

* Relative Volumes:

$$V_{rt} \equiv V_t / V_s$$

(1) $V_{ro}^{CCE} = V_{o(p)} / V_{t(p)}$



(2) $V_{ro}^{CCE} \equiv V_{o(p)} / V_s$ * $f(K_i)$ HP

not reported, calc.

$$V_{ro} = \frac{V_{o(p)}}{V_s} = \underbrace{\frac{V_{o(p)}}{V_{t(p)}}}_{V_{ro}^{CCE(1)}} \cdot \underbrace{\frac{V_{t(p)}}{V_s}}_{V_{rt}}$$

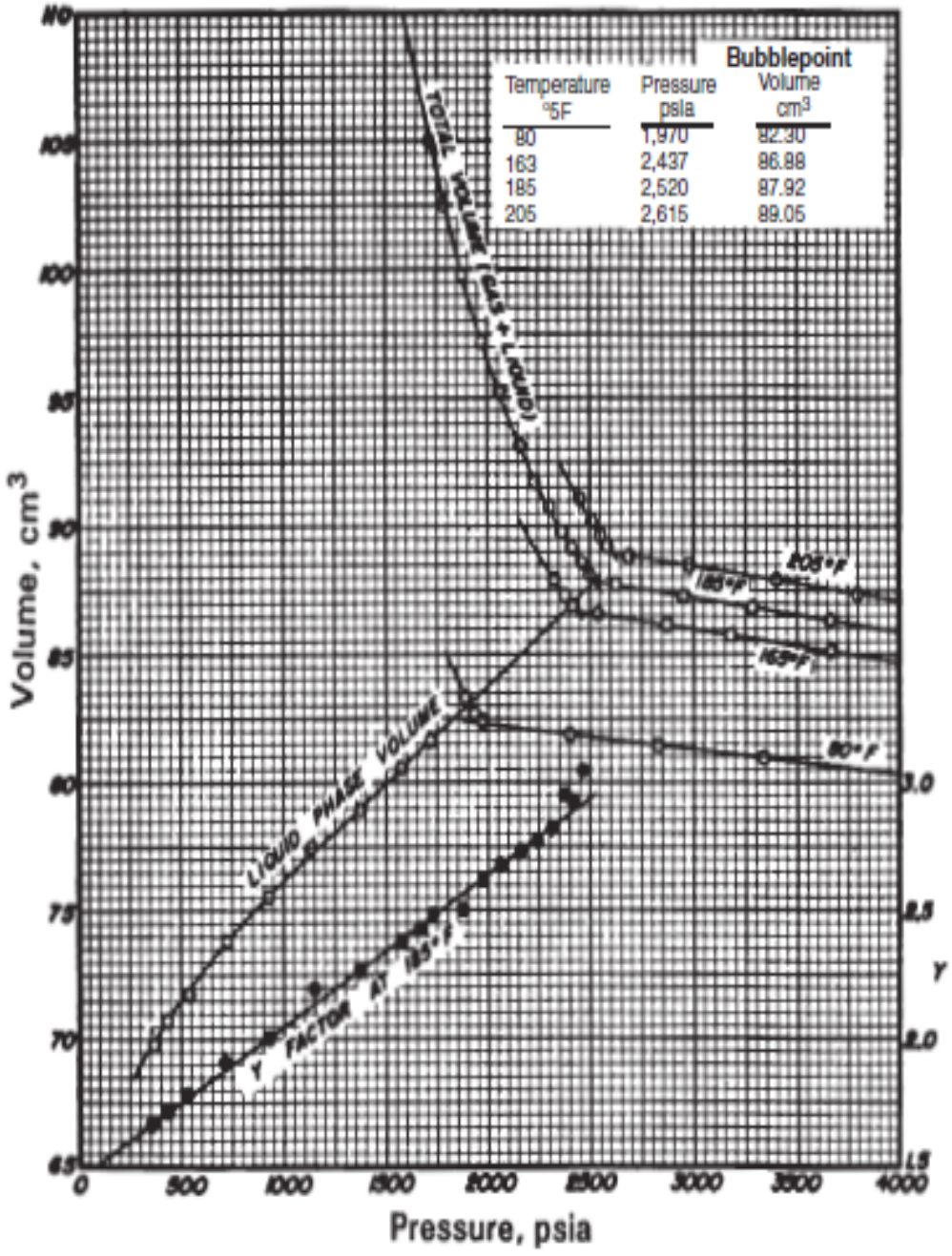
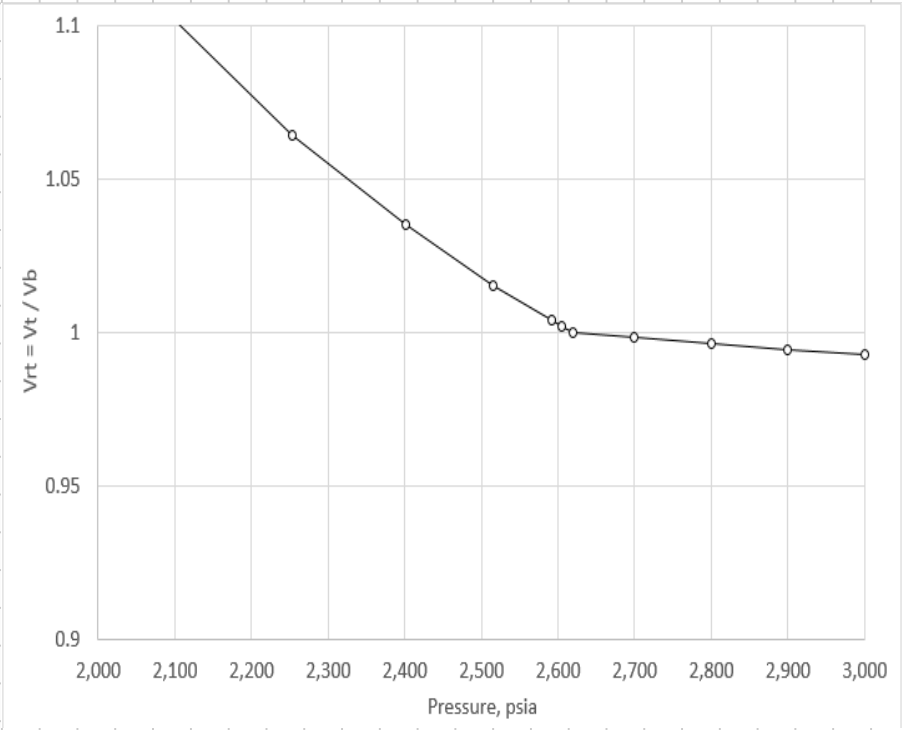
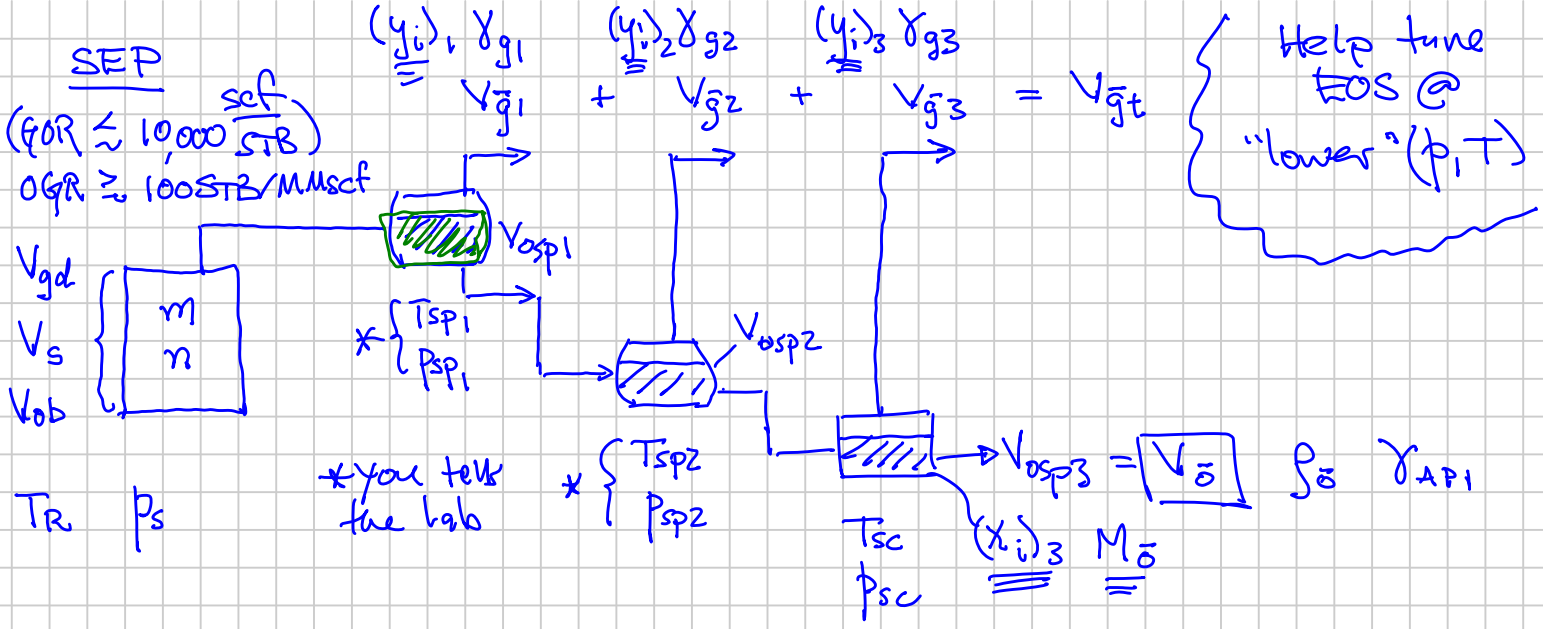


Fig. 6.5—PVT relation and plot of *Y* function for an oil sample at pressures below the bubblepoint.



Ch. 6 Oil



Quantities Reported

Stage	T_{sp}	p_{sp}	GOR(1)	GOR(2)	B_{osp} or $\frac{1}{B_{osp}}$ = SF (sep-vol/STO)	ρ_o	γ_{API}	γ_g
1			+		don't add !	( )		✓
2			+		Quite unreliable (sometimes)	( )		✓
3						$\rho_{\bar{o}}$	API	✓ $\bar{\gamma}_g$
			GOR_t					

$$GOR(1) = V_{\bar{g}}/V_{\bar{o}} \quad [scf/STB] \qquad GOR(2) = V_{\bar{g}}/V_{\bar{o}(T_{sp},p_{sp})} \quad [scf/sep\text{-}bbl]$$

$$B_{osp} = \frac{V_{osp}(T_{sp}, p_{sp})}{V_{\bar{o}}}$$

$$\bar{\gamma}_g = \frac{\sum \gamma_{gk} \cdot GOR_{(i)k}}{GOR_t}$$

Reflects the total average gas mw

Oil (BP): $B_{ob} = \frac{V_{ob}}{V_{\bar{o}}}$ $\left[\frac{m^3}{Sm^3}, \frac{bbl}{STB}\right]$ $R_{sb} = R_{si} = GOR_t$

Gas (DP): • $OGR_t = \frac{10^6}{GOR_t}$ $[STB/MMscf]$ γ_{si} γ_{sd} Initial (DP) Solution OGR

Ch. 7 "B_{gd}" • $\{ B_{gd}(p_d) = \frac{V_{gd}}{V_{\bar{g}t}} \}_{EOD}$

↑ dry (without condensate)

Geologist "B_{oi}" $= \dfrac{HCPV_g \ [bbl]}{ICIP \ [STB]}$

$= \dfrac{B_{gd}(P_i)\left[\frac{ft^3}{scf}\right] \cdot 5.615 \frac{ft^3}{bbl}}{r_{si}\left[\frac{STB}{MMscf}\right]\left[\frac{MMscf}{10^6 scf}\right]}$ $\left[\frac{bbl}{STB}\right]$

If compositions measured: $\underbrace{(y_{gi})_k \ , \ x_{oi}}$

Compositional Mat. Bal.

Lab Flash in Cell z_i vs Back-Calculate $z_i = \dfrac{(\sum (y_i)_k \cdot n_{gk}) + x_{oi} \cdot n_o}{n_{gt} + n_o}$

QC

$(n_g)_k = (GOR_k / (RT_{sc}/p_{sc}))$

$n_o = V_o \cdot \dfrac{\rho_o}{M_o}$

QC: Material Balance on total mass:

Reported ρ_s vs $\rho_s = \dfrac{(\Sigma (m_g)_k) + m_o}{V_s}$

↓ $GOR_t = f(T_{sp_1}, p_{sp_1}, = , =)$

↓ Bob

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

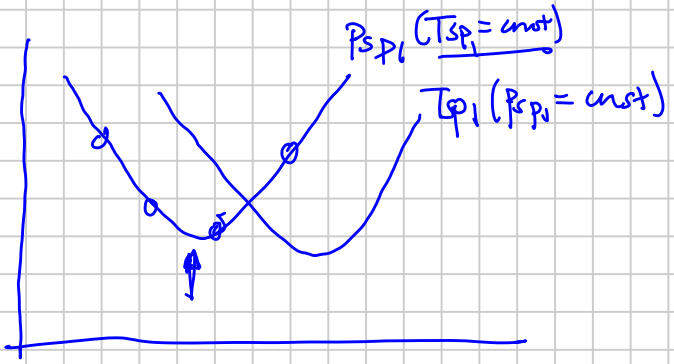
Low-p p_{sp_1} ↑ K_i

High-T T_{sp_i}

BAD

$C_3 \ C_4 \ C_5 \ldots$

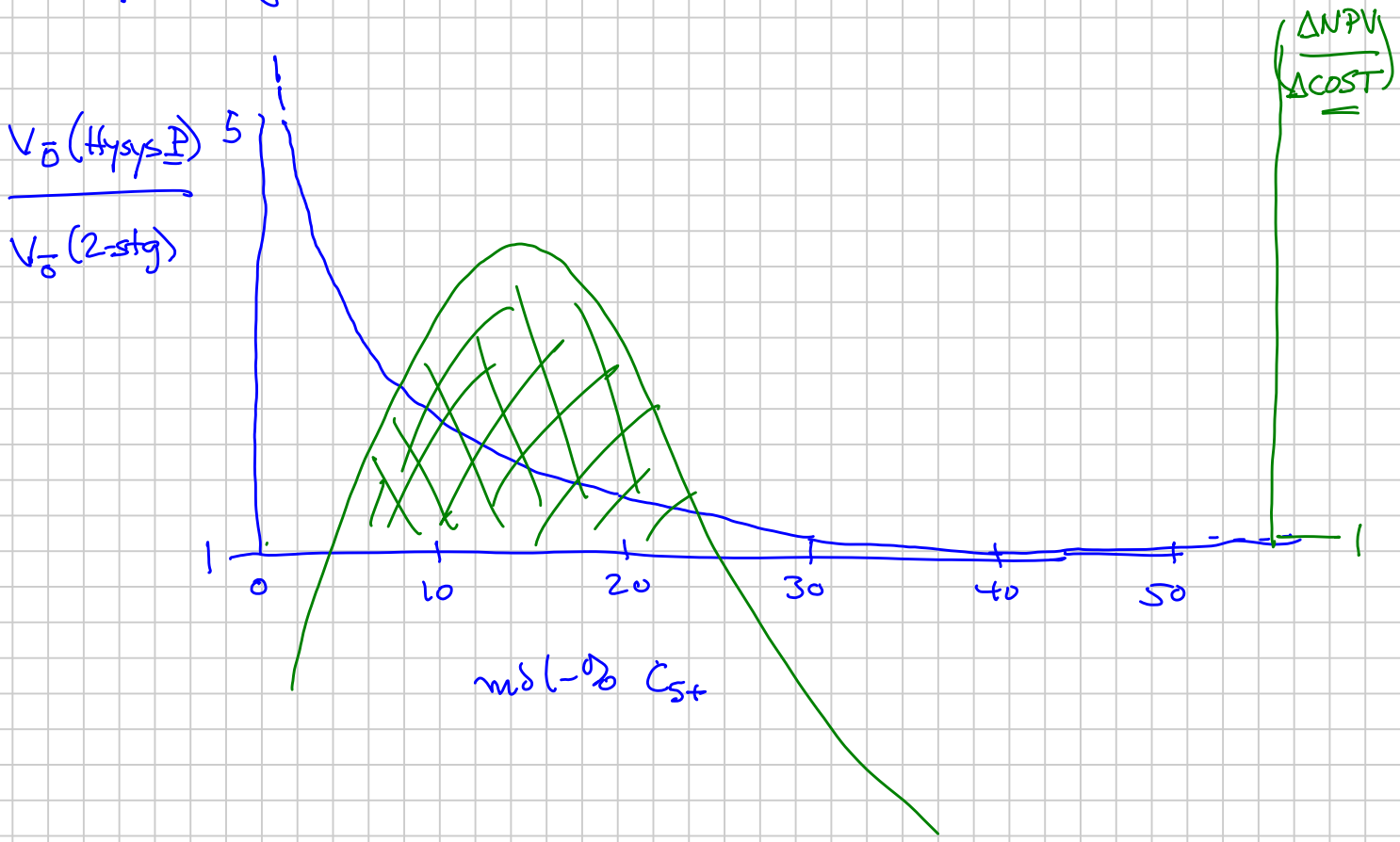
Bob



P_{sp1} T_{sp1}

* Optimal (T_{sp}, P_{sp}) may change over time as the wellstream (field stream) becomes lighter (more methane).

* Optimal $V_{\bar{o}}$ is much more sensitive to (T_{sp}, P_{sp}) for lighter (leaner) streams:



DLE

① Only used for oils

② Blind PVT cell

③ To get pressure dependence below p_b of

- ✓ – S_o (only important high k)
  → μ_o
- ✓ – V_o shrinkage
- ✓ – Solution gas release

} $= S_o^n \propto k_{ro}$ } λ_o

④ Procedure is identical to SEP

EXCEPT • $T_{sp} = T_R$

• $N_{stages} \sim 8$ (5-10)

• Last stage is a bleeding process

Reported Quantities:

p	$\frac{V_o(p)}{V_{or}} = B_{od}$	$\frac{\Delta V_g}{V_{or}} = \Delta R_{sd}$	R_{sd} (Gas Remaining in Solution)	ρ_o	Z_g	γ_g	(y_i)
$p_1 = p_b$	$B_{od,b}$	0	1000				
p_2		120	880				
p_3		100	780				
⋮							
$p_N = p_{sc}$	1.0x	50	0				
		$(\sum \Delta R_{sd})$ =	$R_{sd,b}$ = 1000 scf/resbbl				

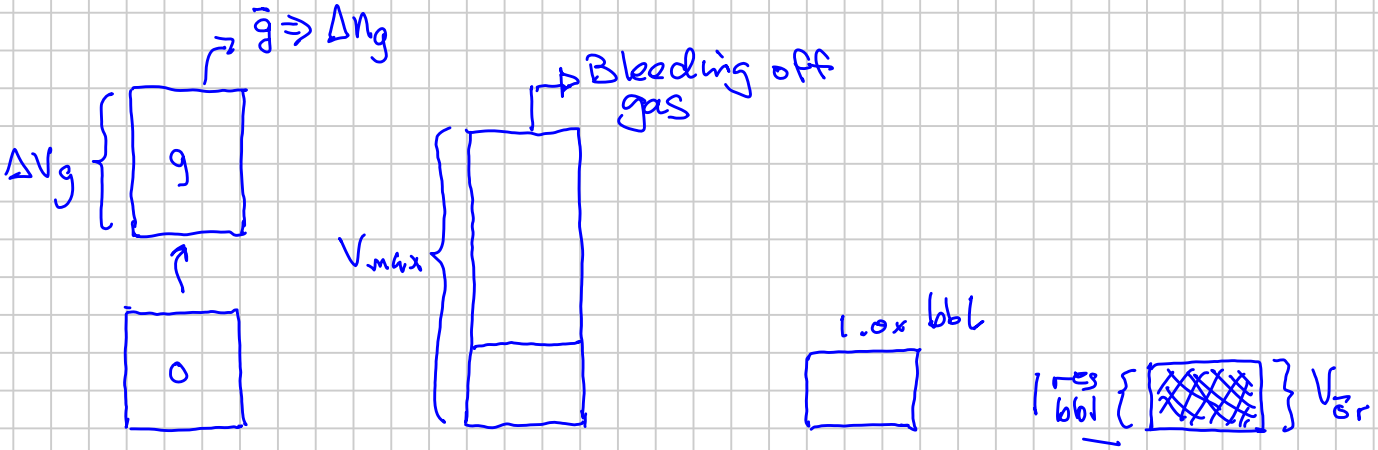
$B_{od,b} > B_{ob}$ (SEP)

$R_{sd,b} > R_{sb}$ (SEP)

$API_d < API$ (SEP)

ρ_o = calc. by material balance (Ch. 6) = $\dfrac{\rho_{or} + \sum \Delta R_{sd,k}\, \gamma_{g,k}}{B_{od,k}}$

$Z_g = \dfrac{p\, \Delta V_g}{\Delta n_g\, R\, T_R}$



T_R

P_{N-1}

~ 250 psi

$P_N \rightarrow P_{sc} \rightarrow$ 1 atm T_R

T_R

This is not used in FVT simulators

Emulate this by adding 5-10 steps from 250-15 psi

$P_{N-1} \rightarrow P_N = P_{sc}$

* Higher T_R > 250°F, Light Oils > 40°API $\Big\}$ $(B_{od}, R_{sd})_{EOS} >> (B_{od}, R_{sd})_{lab}$

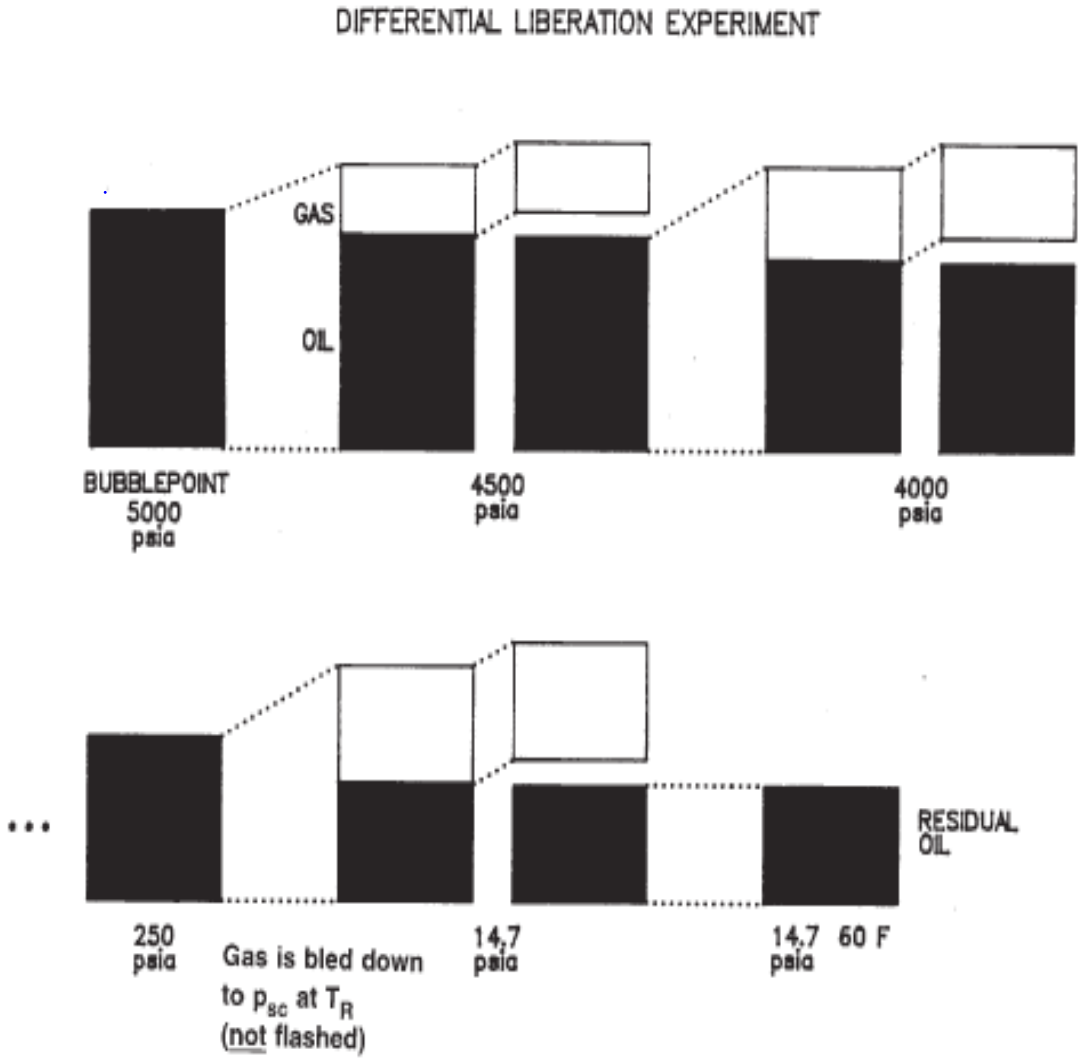


Fig. 6.6—Schematic of DLE experiment.

$$B_{td} = \frac{V_g + V_o}{V_{or}} = B_{od} + (R_{sd,b} - R_{sd})\, B_g$$

TABLE 6.11—DLE DATA FOR GOOD OIL CO. WELL 4 OIL SAMPLE

Differential Vaporization

Pressure (psig)	Solution GOR (scf/bbl*)	Relative Oil Volume (RB/bbl*)	Relative Total Volume (RB/bbl*)	Oil Density (g/cm³)	Deviation Factor Z	Gas FVF (RB/bbl*)	Incremental Gas Gravity
2,620	854	1.600	1.600	0.6562			
2,350	763	1.554	1.665	0.6655	0.846	0.00685	0.825
2,100	684	1.515	1.748	0.6731	0.851	0.00771	0.818
1.850	612	1.479	1.859	0.6808	0.859	0.00882	0.797
1,600	544	1.445	2.016	0.6889	0.872	0.01034	0.791
1,350	479	1.412	2.244	0.6969	0.887	0.01245	0.794
1,110	416	1.382	2.593	0.7044	0.903	0.01552	0.809
850	354	1.351	3.169	0.7121	0.922	0.02042	0.831
600	292	1.320	4.254	0.7198	0.941	0.02931	0.881
350	223	1.283	6.975	0.7291	0.965	0.05065	0.988
159	157	1.244	14.693	0.7382	0.984	0.10834	1.213
0	0	1.075		0.7892			2.039
		1.000**					

DLE Viscosity Data at 220°F

Pressure (psig)	Oil Viscosity (cp)	Calculated Gas Viscosity (cp)
5,000	0.450	
4,500	0.434	
4,000	0.418	
3,500	0.401	
3,000	0.385	
2,800	0.379	
2,620	0.373	
2,350	0.396	0.0191
2,100	0.417	0.0180
1,850	0.442	0.0169
1,600	0.469	0.0160
1,350	0.502	0.0151
1,100	0.542	0.0143
850	0.592	0.0135
600	0.654	0.0126
350	0.783	0.0121
159	0.855	0.0114
0	1.286	0.0093

Gravity of residual oil = 35.1°API at 60°F.

*Barrels of residual oil.

**At 60°F.

CVD

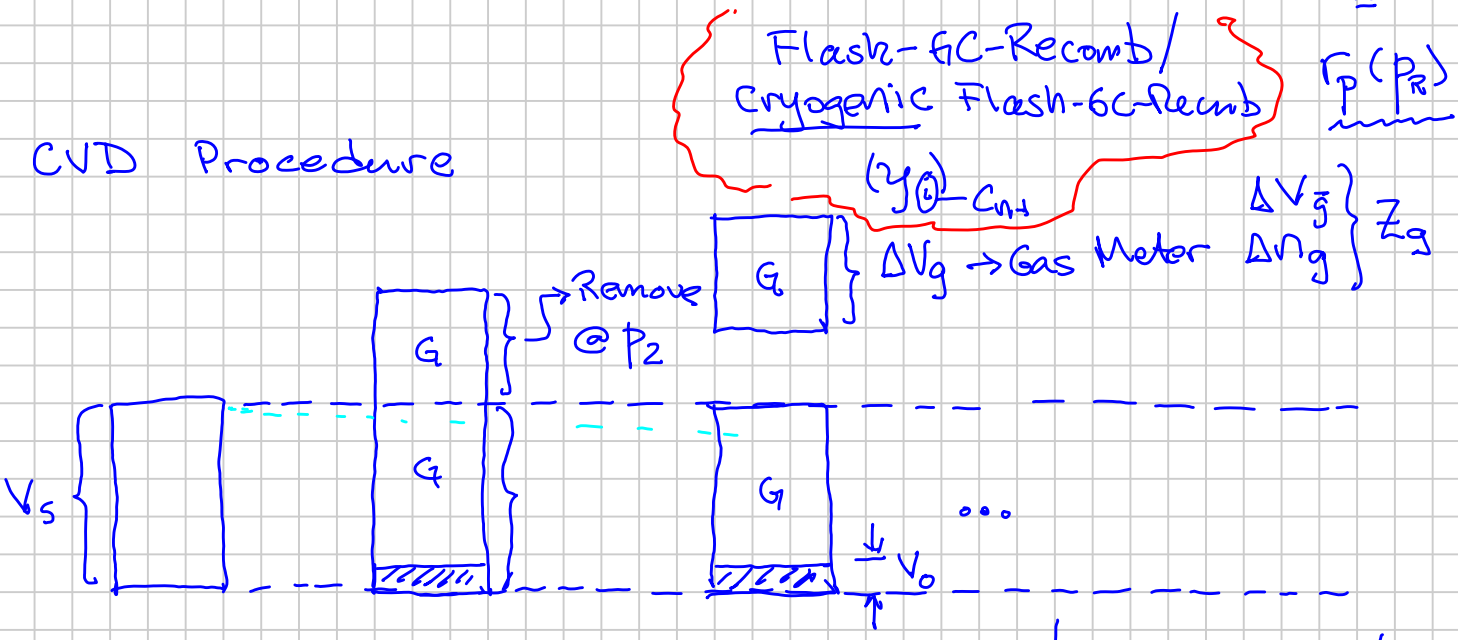
* Used for "gas condensates / volatile-near critical oils"
  SSF GOR ≳ 2500-2750 scf/STB

* Higher accuracy to gas compositions $y_i\ (p<p_s)$ ↑ QC!
  $C_{n+}\ (C_{6+}-C_{7+})$

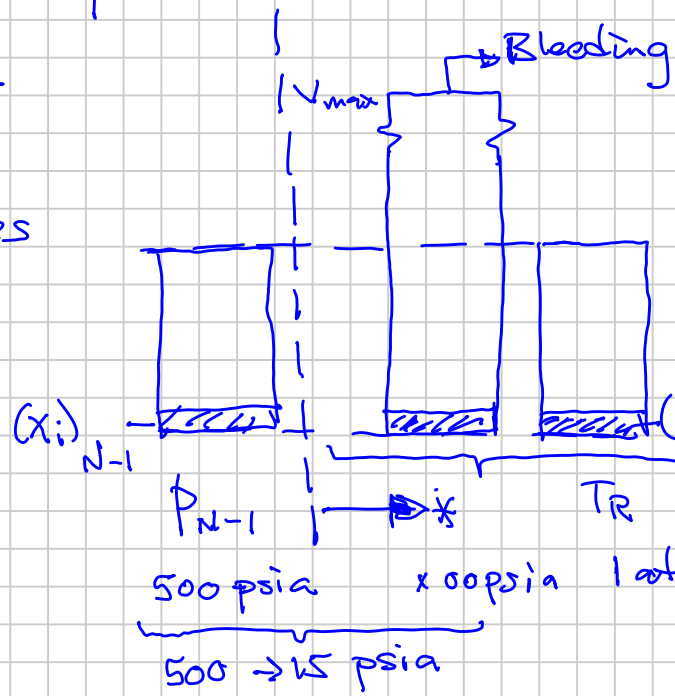
* Gas Condensate fluid systems - CVD data $y_{n+}(p<p_d)$ is the only real important PVT data not well described / Known.
  Solution GOR CVD $[\ r_s(p)\ ] \simeq r_p(p_R)$

Flash-GC-Recomb / Cryogenic Flash-GC-Recomb

CVD Procedure



Repeated G-10 times



QC Component material balances not affected by bleeding process

* Don't use p_i "data" in EOS tuning!

Quantities Reported

p | $\frac{V_o}{V_s} = V_{ro}$ (CVD) % | $[y_i]$ | M_{n+} γ_{n+} ~ | $\frac{n_p}{n_d}$ [mol/mol] % [scf/scf] | $[Z_g]$ SK ✓ | $[Z_2]$

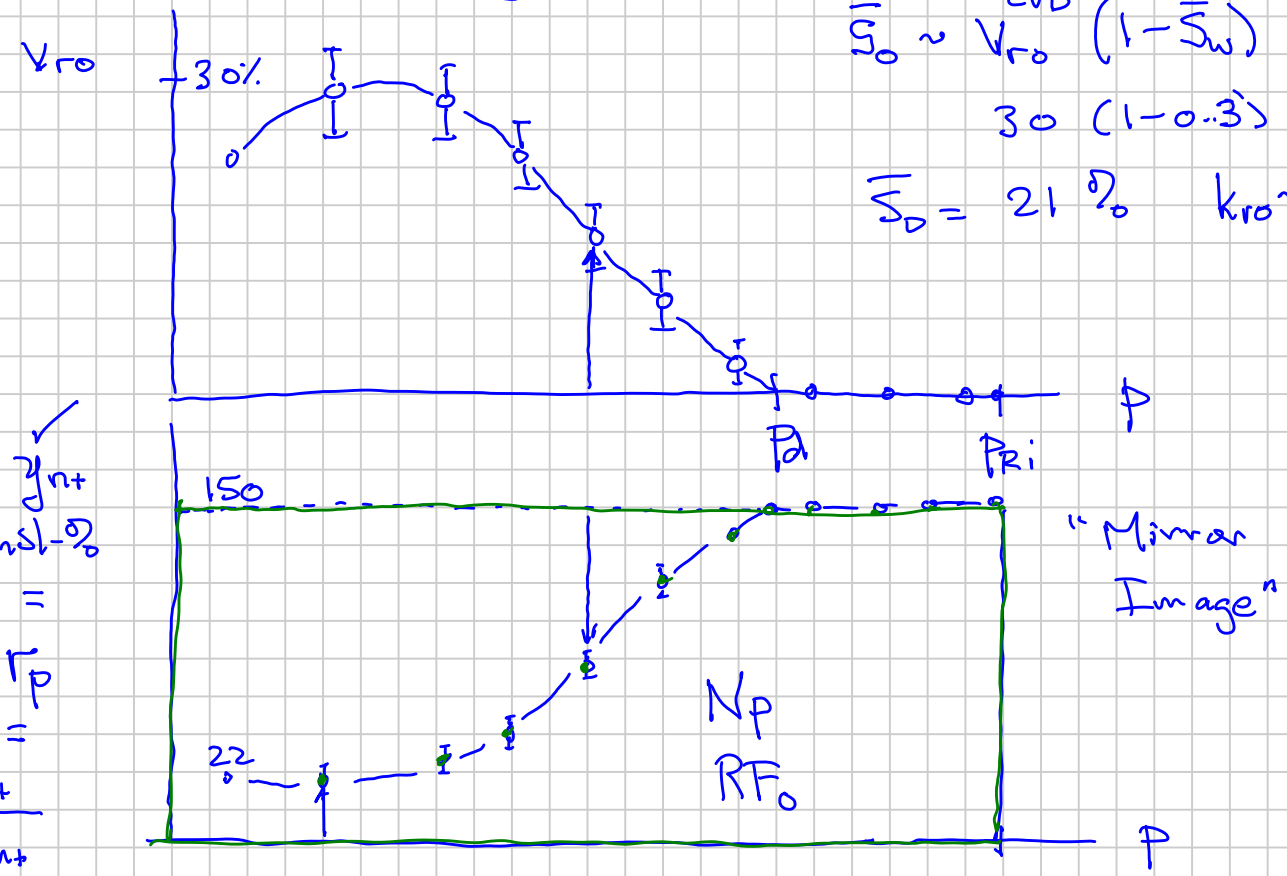
$p_i = p_d$

C

$\bar{S}_o \sim V_{ro}^{CVD} (1 - \bar{S}_w)$

$30\ (1 - 0.3)$

$\bar{S}_D = 21\%$ $\quad k_{ro} \sim 0$



How to QC y_{n+} data in CVD:

① Forward Material Balance
- CL Ruedelberger-Hinds Whitson-Torp

$$n_i(z_i)_1 = \Delta n_g\, y_i + n_g\, y_i + \hat{n}_o\, x_i$$

Back-Calc

$$V_s \cdot (1 - V_{ro}) = \underbrace{V_g, p, T, Z_g}_{n_g}$$

$$\hat{n}_o = n - \Delta n_g - n_g$$

$$K_i \simeq \frac{y_i}{\tilde{x}_i}$$

> 150 STB/MMscf

useful, accurate ONLY if you have "richer" G.C.

Very sensitive V_{ro} ✓

* ② Backward Material Balance BEST QC

N-1 or N

$$n_{or} = V_{ro} \cdot \left(\frac{S_o}{M_o}\right)$$

✓ ✓

$(x_i)_{\substack{N \\ N-1}}$

$$\text{Initial } (z_i) = (z_{cell})_{k=1} = \left[n_{or} (x_i)_{or} + \sum_{l=N-1}^{k=1} \Delta n_{g,l} y_{i,l} \right] \Big/ \left(n_{or} + \sum_{l=N-1}^{1} \Delta n_g \right)$$

vs

Lab (z_i) ⇒ Determine Lab "Losses" by component C_{6+}

$(z_{6+})_{Lab}$ = 12 mol-% . OGR = 200 STB/MMscf

$(z_{6+})_{BMB}$ = 10 mol-% : = 160

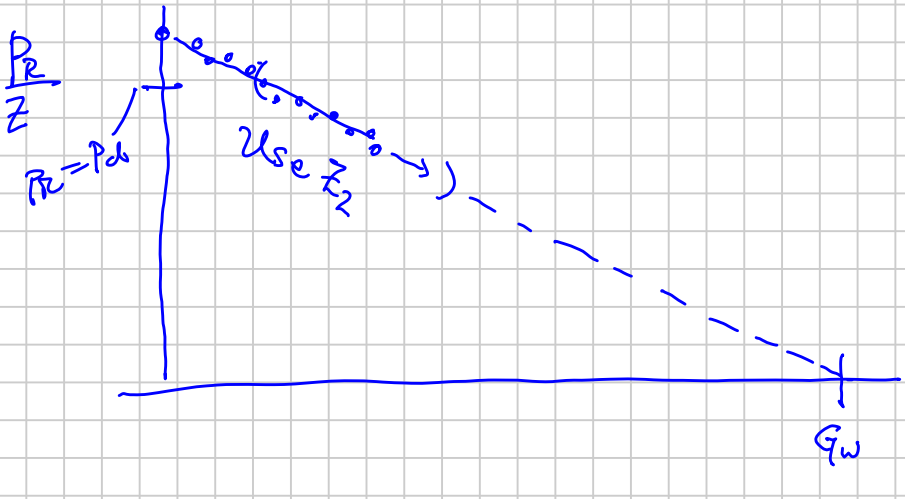
Two-Phase Z-factor Z_2

* Only be used for one application!
  - Using a traditional Gas Material Balance

$$\left[1 - c_e(p_i - p)\right]\frac{p}{z} = \left(\frac{p}{z}\right)_i\left[1 - \frac{G_p}{G}\right]$$

Water

$\frac{p}{z}$ to use here at $p_R < p_d$: Z_2



$$G_w = \underbrace{|G|}_{G_d}P + \underbrace{|C|}_{N}P.\left[\left(\frac{\rho_{\bar{o}}}{M_{\bar{o}}}\right)\left(\frac{RT_{sc}}{p_{sc}}\right)\right]$$

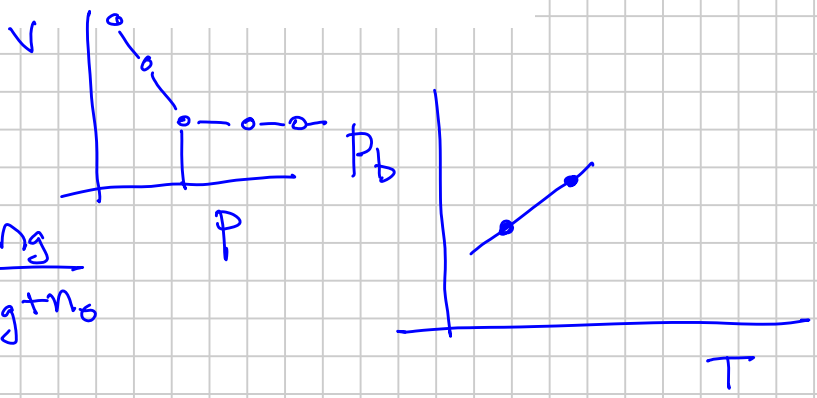
$$G_{p_w} = G_{pd} + N_p\left(\frac{\rho_{\bar{o}}}{M_{\bar{o}}}\right)\left(\frac{RT_{sc}}{p_{sc}}\right)$$

G_{p_w}: wet gas

Separator Liquid:	BP Pressure	Temperature
Cylinder ID No. W-209*	595 psig	77 °F
Cylinder ID No. W-357	594 psig	77 °F

$P_{sp} = 650$ psi
$T_{sp} = 94$°F

Report Date: 7/17/2008



$GOR_{sp}, \rho_{osp}, M_{osp} \Rightarrow F_g = \frac{n_g}{n_g + n_o}$ Eq. 6

$z_{wi} = F_g y_i + (1 - F_g) x_i \Rightarrow c_i \Rightarrow F_g = \frac{z_i - x_i}{y_i - x_i} = 0.7805$

	SEPARATOR GAS		SEPARATOR OIL		WELLSTREAM	
Component	y_i Mole%	* GPM	x_i Mole %	Liquid Volume %	z_{wi} Mole %	* GPM
Hydrogen Sulfide	0.000	0.000	0.000	0.000	0.000	0.000
Nitrogen	0.484	0.000	0.072	0.018	0.393	0.000
Carbon Dioxide	2.037	0.000	0.847	0.331	1.776	0.000
Methane	82.531	0.000	17.472	6.788	68.250	0.000
Ethane	7.266	1.933	6.165	3.779	7.024	1.868
Propane	5.155	1.411	11.852	7.476	6.625	1.813
Iso-butane	0.779	0.253	3.689	2.765	1.418	0.461
N-butane	1.047	0.328	6.843	4.942	2.319	0.727
2-2 Dimethylpropane	0.000	0.000	0.066	0.058	0.014	0.006
Iso-pentane	0.228	0.083	3.026	2.538	0.842	0.306
N-pentane	0.187	0.067	3.169	2.631	0.842	0.303
2-2 Dimethylbutane	0.004	0.002	0.087	0.083	0.022	0.009
Cyclopentane	0.022	0.006	0.000	0.000	0.017	0.005
2-3 Dimethylbutane	0.000	0.000	0.473	0.444	0.104	0.042
2 Methylpentane	0.037	0.015	1.125	1.070	0.276	0.114
3 Methylpentane	0.019	0.008	0.679	0.636	0.164	0.067
Other Hexanes	0.000	0.000	0.000	0.000	0.000	0.000
n-Hexane	0.039	0.016	1.614	1.521	0.385	0.157

HOFFMAN PLOT

EQUILIBRIUM CHECK of SEPARATOR LIQUID and GAS COMPOSITIONAL ANALYSES

Separator Pressure = 650 psig
Separator Temperature = 94 °F

Components	Gas (X) Mole %	Oil (Y) Mole %	Equil. Ratio (K=Y/X)	K*Psep (psiA)	Normal BP (NBP) °R	$T_{NBP}^{-1} - T_{SEP}^{-1}$	Critical Pressure (Pc) psiA	Critical Temperature (Tc) °R	B-Factor	Graph Results	
										B(1/Tb-1/Tsp)	Log(K*Psep)
N2	0.484	0.072	6.758	4491.50	139	0.005373	493	227	551	2.958	3.652
CO2	2.037	0.847	2.404	1598.02	350	0.001048	1071	548	1811	1.898	3.204
C1	82.531	17.472	4.724	3139.57	201	0.003169	668	343	805	2.552	3.497
C2	7.266	6.165	1.179	783.39	332	0.001204	708	550	1413	1.701	2.894
C3	5.155	11.852	0.435	289.10	416	0.000598	616	666	1799	1.076	2.461
IC4	0.779	3.689	0.211	140.35	471	0.000319	529	735	2038	0.650	2.147
NC4	1.047	6.843	0.153	101.70	491	0.000231	551	765	2158	0.498	2.007
IC5	0.228	3.092	0.074	49.01	542	0.000040	490	829	2383	0.095	1.690
NC5	0.187	3.169	0.059	39.22	557	-0.000009	489	845	2483	-0.023	1.594
C6	0.121	3.978	0.030	20.22	615	-0.000181	437	913	2784	-0.504	1.306
C7+	0.165	42.822	0.004	2.56	763	-0.000496	332	1070	3607	-1.789	0.408
Total	100.000	100.000									

Hoffman - Crump - Hocott

$$K_i = \frac{P_{vi}(T)}{p}$$ ✓

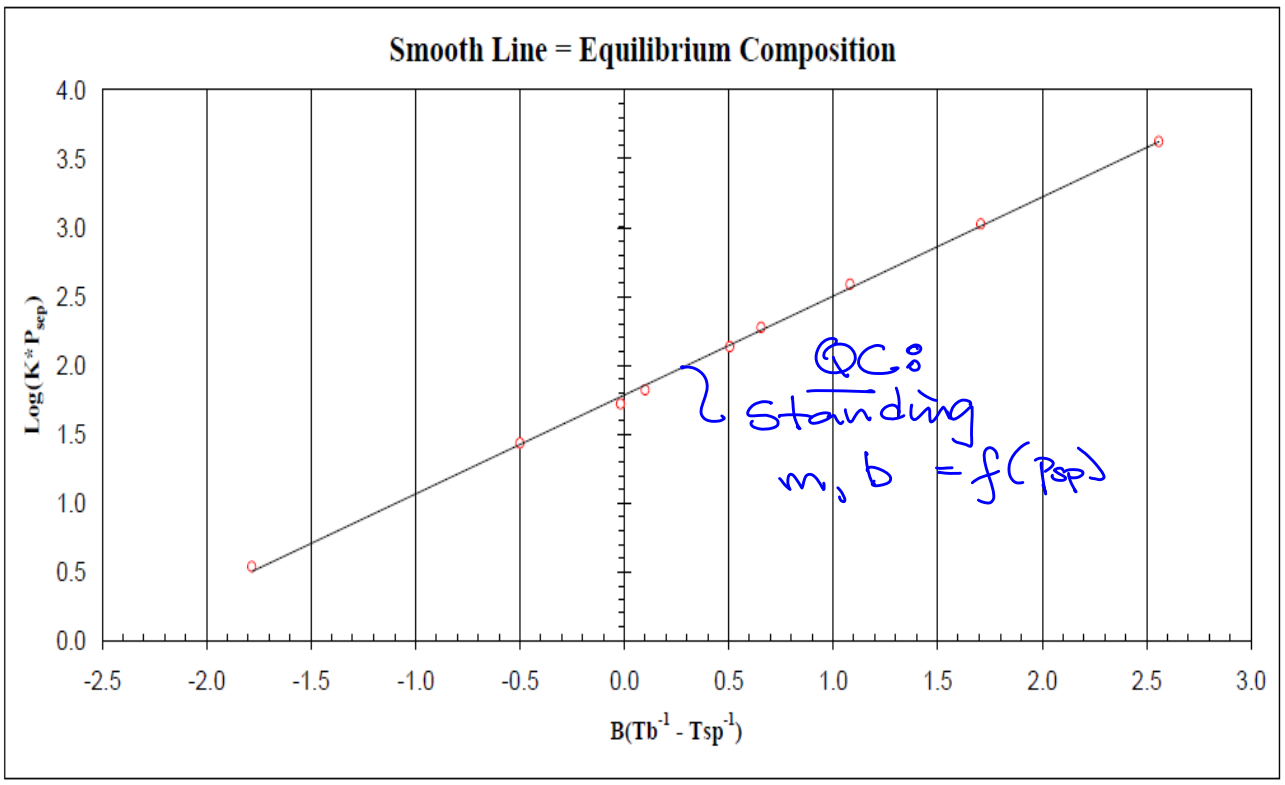
$$K_i p = A_0 + A_1 F_i$$

$$F_i = b_i \left(\frac{1}{T_{bi}} - \frac{1}{T_{sp}} \right)$$

$$b_i = \frac{\log (P_{ci}/P_{sa})}{\left(\frac{1}{T_{bi}} - \frac{1}{T_{ci}} \right)}$$

Edmister $P_{vi}(P_{ci}, T_{ci}, T_{bi})$ ✓

Ch. 3


Smooth Line = Equilibrium Composition
Log(K*P_sep)
B(Tb^-1 - Tsp^-1)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-2.5
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
QC: Standing
m, b = f(Psp)

SEPARATOR CONDITIONS and FLUID PROPERTIES						
Conditions	Pressure psia	Temperature °F	GOR (1)	Separator Oil Volume Factor (2)	Oil Density (3)	Gas Specific Gravity (4)
1st Stage Separator	665	94	N/A	1.2573	0.7071	0.705
2nd Stage Separator	91	80	263	N/A	N/A	0.926
3rd Stage Separator	45	120	47	N/A	N/A	1.264
Ambient Lab Condition	14.65	75	104	1.0079	0.7888	1.758
Stock Tank	14.65	60	0	1.0000	0.7961	1.758
TOTALS	-----	-----	414		-----	-----

Stock Tank Oil Gravity: 46.06 °API at 60 °F

(1) Gas-Oil Ratio (GOR) is the cubic feet of gas at standard conditions per barrel of stock tank oil.
(2) Barrels of oil at indicated separator conditions per barrel of stock tank oil.
(3) Oil Density (g/cc) at indicated separator conditions.
(4) Air = 1.000

Test 4320

$$GOR_w = GOR_1 + 414 = 4734 \frac{scf}{STB}$$

$\left(\frac{scf}{STB}\right)$ scf/MMscf

$$CGR_t = r_{si} = \frac{10^6}{4734} = 211 \quad \frac{STB}{MMscf}$$

scf/STB

TABLE 3

PRESSURE-VOLUME RELATION OF A 3436 Scf/Sep Bbl RESERVOIR FLUID AT 263 °F (Constant Composition Expansion)

Pressure, (psig)		Relative Volume	Density, (g/cc)	Y-Function (1)	Retrograde Liquid Volume % of HC Pore Volume (2)	Retrograde Liquid Volume Bbls / MMscf (3)	Gas Deviation Factor, Z_g	Gas Expansion Factor, (4)
11000		0.82736	0.47758	N/A	N/A	N/A	1.77731	1.69183
10440	Pres	0.83715	0.47199	N/A	N/A	N/A	1.70691	1.67193
10000		0.84486	0.46769	N/A	N/A	N/A	1.65013	1.65657
9000		0.86686	0.45581	N/A	N/A	N/A	1.52404	1.61426
8000		0.89274	0.44260	N/A	N/A	N/A	1.39542	1.56715
7000		0.92595	0.42673	N/A	N/A	N/A	1.26675	1.51055
6500		0.94639	0.41751	N/A	N/A	N/A	1.20243	1.47769
6000		0.97085	0.40699	N/A	N/A	N/A	1.13883	1.44019
5535	Psat	1.00000	0.39513	N/A	0.00%	0.000	1.08234	1.39792
5178		1.03101	N/A	2.21679	4.26%	30.252	N/A	N/A
4774		1.07253	N/A	2.19115	15.84%	112.422	N/A	N/A
4280		1.13887	N/A	2.10425	21.07%	149.544	N/A	N/A
3898		1.20738	N/A	2.01749	22.84%	162.094	N/A	N/A
3456		1.31271	N/A	1.91560	23.83%	169.096	N/A	N/A
3070		1.43810	N/A	1.82404	24.61%	174.671	N/A	N/A
2446		1.74876	N/A	1.67658	24.16%	171.474	N/A	N/A
1827		2.30634	N/A	1.54126	22.97%	163.019	N/A	N/A
1383		3.05722	N/A	1.44403	21.93%	155.621	N/A	N/A
938		4.56767	N/A	1.35256	20.78%	147.430	N/A	N/A

(1) Y - Function = Dimensionless Compressibility = $(P_{sat} - P_i) * [P_i * (RV_i - 1)]^{-1}$

(2) Retrograde liquid volume at the indicated pressure and reservoir temperature as a percent of the hydrocarbon pore volume at the dew point pressure and reservoir temperature.

(3) Retrograde liquid volume at the indicated pressure and reservoir temperature (Bbls) per volume of gas (MMscf) at the dew point pressure and reservoir temperature.

(4) Gas Expansion Factor = the volume of surface gas at standard conditions (Mscf) produced from one barrel of undersaturated gas at the indicated pressure and reservoir temperature.

TABLE 4

RESERVOIR GAS DEPLETION STUDY AT 263 °F

Reservoir Pressure, psig	(D.P.) 5535	4500	3500	2500	1700	900	0
Wellstream Components	mole %	mole %	mole %	mole %	mole %	mole %	mole %
Hydrogen Sulfide	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nitrogen	0.393	0.405	0.433	0.442	0.437	0.428	0.335
Carbon Dioxide	1.776	1.829	1.863	1.899	1.936	1.945	1.612
Methane	68.250	71.913	74.339	75.538	76.049	74.723	60.118
Ethane	7.024	7.178	7.244	7.464	7.621	7.691	7.178
Propane	6.625	6.501	6.501	6.501	6.501	7.112	8.091
Iso-butane	1.418	1.352	1.312	1.300	1.324	1.462	1.991
N-butane	2.319	2.178	2.113	2.113	2.113	2.360	3.243
Iso-pentane	0.857	0.800	0.766	0.724	0.690	0.815	1.213
N-pentane	0.842	0.787	0.757	0.716	0.681	0.762	1.151
Hexanes	0.968	0.857	0.771	0.701	0.647	0.701	1.268
Heptanes Plus	9.529	6.200	3.900	2.600	2.000	2.000	13.800
TOTALS	100.000	100.000	100.000	100.000	100.000	100.000	100.000

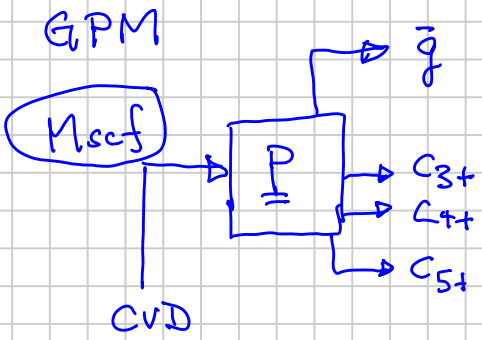
HEPTANES PLUS (C_{7+}) FRACTION CHARACTERISTICS							
Molecular Weight	169.530	149.703	136.501	126.627	120.849	116.400	131.537
Specific Gravity	0.8163	0.8013	0.7897	0.7803	0.7746	0.7699	1.3869

CONDENSED RETROGRADE LIQUID VOLUME							
HC Pore Volume %	0.000	17.000	22.842	23.832	22.309	19.063	14.967
Bbls/MMscf of DP Gas	0.000	120.639	162.094	169.122	158.316	135.277	106.213

GAS DEVIATION FACTOR							
Equilibrium Gas	1.0823	0.9202	0.8515	0.8369	0.8568	0.9069	N/A
Two-Phase	1.0823	0.9568	0.8786	0.8169	0.7645	0.6848	N/A

CUMULATIVE PRODUCED WELLSTREAM VOLUME							
Vol % of Initial DP Gas	0.000	7.976	21.980	39.965	56.259	73.951	93.845

GPM FROM CVD WELLSTREAM COMPOSITIONS							
Propane plus (C_{3+})	10.246	7.476	5.859	5.002	4.617	4.972	12.546
Butanes plus (C_{4+})	8.432	5.697	4.080	3.223	2.837	3.026	10.332
Pentanes plus (C_{5+})	7.245	4.575	2.991	2.138	1.744	1.811	8.668



gallons / Mscf wellstream

$$OGR = \frac{(V_{3+})_L}{V_{\bar{g}}(C_{2-})}$$

$$GPM = \left[y_{3+} \cdot \frac{(M_{3+})}{(\rho_{L3+})} \right] (17)$$

gallons

GPM ↑

Ideal Volume Mixing

$\frac{1000 \text{ scf}}{379 \text{ scf/lb mole}}$