Note Title 3/10/2017

Oil PVT Properties Used in Engineering

"Black Oil PVT" – Traditional (pre-1970)

@ T_R

p	B_o	R_s	μ_o	B_g	μ_g	$r_s = 0$
{SI U}	Oil Phase			GAS Phase		

FVF

B_o = Oil Formation Volume Factor, $\frac{\text{Res. Volume}}{\text{STO Volume}}$

$$= \frac{V_o(p, T_R)}{V_{\bar{o}}}$$

$[m^3/Sm^3]$ $\begin{bmatrix} RB/STB \\ bbl/STB \end{bmatrix}$

* Ekofisk $B_{oi} \sim 2$ RB/STB

$$R_s = \frac{V_{\bar{g}}}{V_{\bar{o}}} = \text{Solution Gas-Oil Ratio}$$

$V_{\bar{g}}$ in solution in oil phase V_o

$[Sm^3/Sm^3]$ [scf/STB]

[Mscf/STB]

* Ekofisk: $\sim 1500 \frac{scf}{STB}$

* SEP Test B_{ob} R_{sb}

Starts @ p_b

$$B_{ob} = \frac{V_{ob}}{V_{\bar{o}}}$$

* CCE : $\left[V_{rt} = \frac{V_t}{V_s} \right]$ Lab Table

OIL, $p_s = p_b$
$V_s = V_{ob}$
$p > p_b$

$$V_{rt} = \frac{V_o(p)}{V_{ob}}$$

$p = p_{Ri}$
(Eko: 7000 psia)

$$V_{rt,i} = \frac{V_{oi}}{V_{ob}}$$

$$B_{oi} = \frac{V_{oi}}{V_{\bar{o}}}$$

$$= \frac{V_{oi}}{\cancel{V_{ob}}} * \frac{\cancel{V_{ob}}}{V_{\bar{o}}}$$

"0.9" "2.1"

$$= V_{rt,i} \cdot B_{ob}$$

Eko ~ 2.0 RB/STB

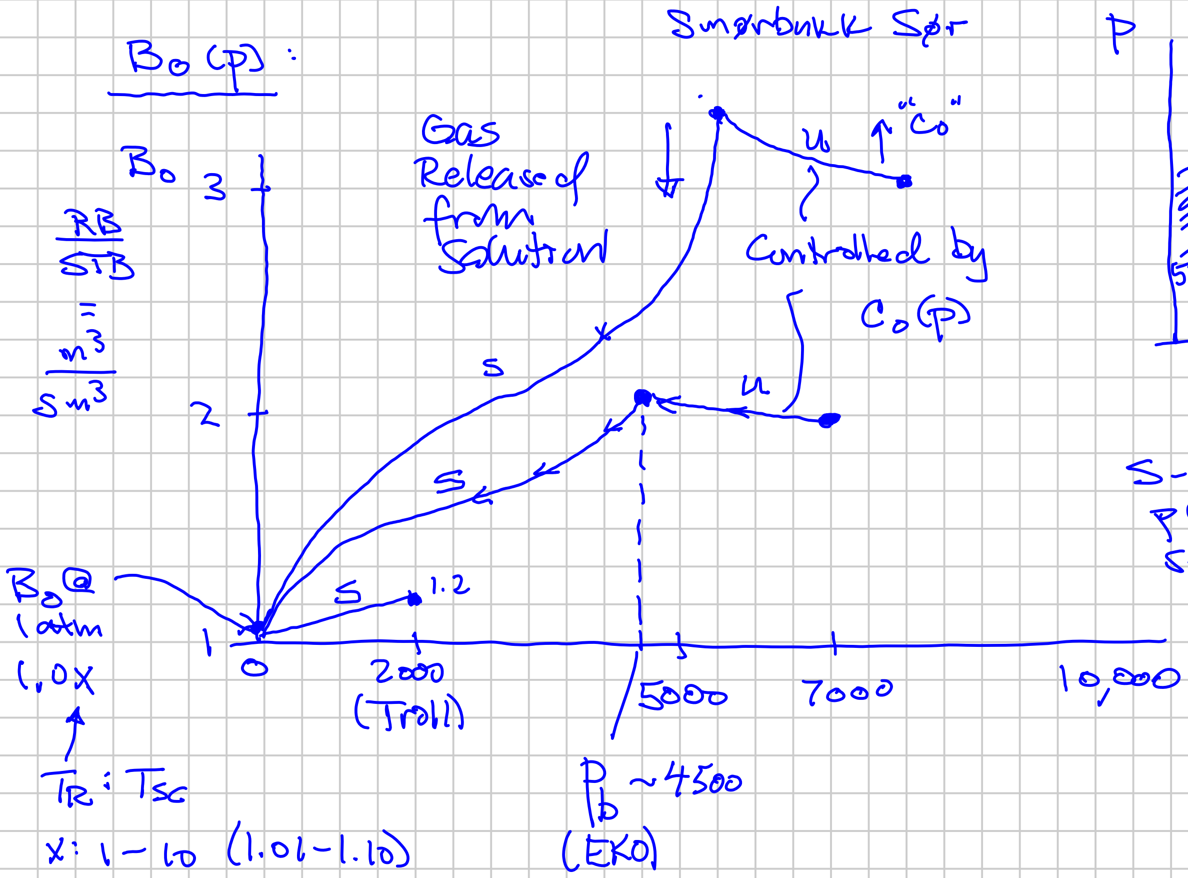
IOIP
OOIP
STOIP
OIP
STIIP

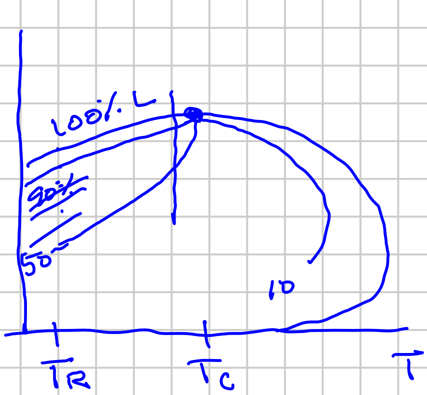
$$N = \frac{\overset{\text{Geo-folks}}{HCPV}}{B_{oi}}$$

Much lower uncertainty

HCPV ± $\underbrace{\phi \quad S_w \quad A \quad h}_{\text{Lots of Uncertainty}}$

Pressure Dependence of BOPVT properties





S-shape more pronounced and severe $T_R \to T_c$

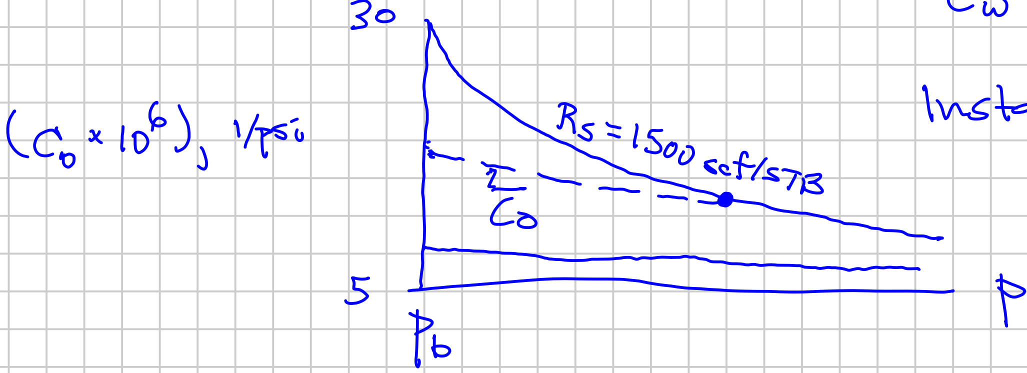
$\underline{u_i}$: $c_o = -\frac{1}{V_o}\left(\frac{dV_o}{dp}\right)_{T_R} \sim 3-50\cdot10^{-6}\ \frac{(\text{vol/vol})}{\text{psi}}$

psi → sip

$\longrightarrow f(R_s, \gamma_{API})$

$c_w \sim 3\text{-}5\cdot10^{-6}$

Instantaneous $c_o(p)$



$$RF_o = \frac{N_p}{N} \approx \left[c_t \underbrace{(p_{Ri} - p_R)} \right]$$

CCE test

$$c_o(p > p_b) = \frac{1}{V_{rt}} \left(\frac{dV_{rt}}{dp} \right)$$

@ $p_R > p_b$

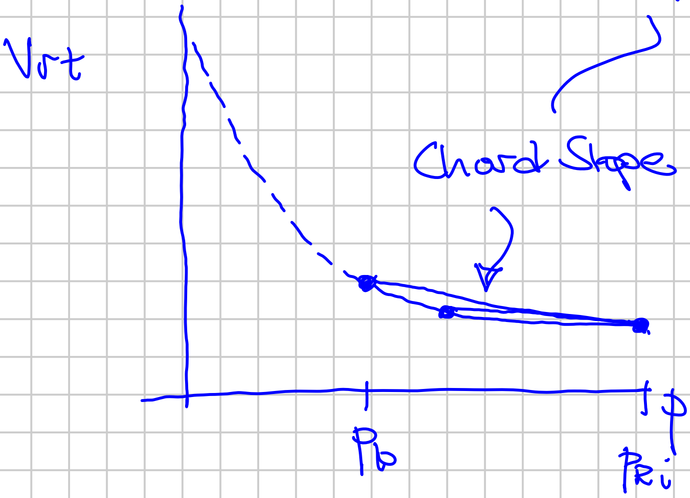
$$c_t = \bar{c}_f(p) + \bar{c}_w \cdot \bar{S}_w + \bar{c}_o(p) \underbrace{(1 - \bar{S}_w)}_{\bar{S}_o}$$

formation rock "pore"

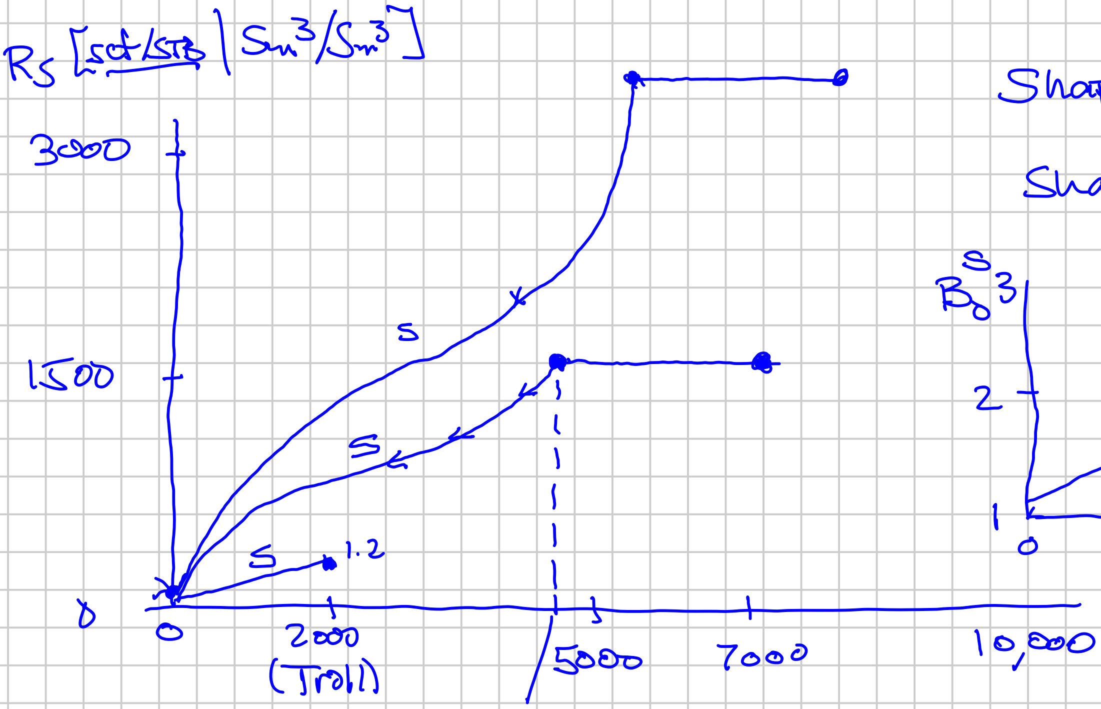
high for Chalk $25\text{-}30^{+} \cdot 10^{-6}\ psi^{-1}$

Cumulative Oil Compressibility

$$= \frac{1}{V_{oi}} \cdot \frac{(V_{oi} - V_o)}{\underbrace{(p_{Ri} - p_R)}}$$

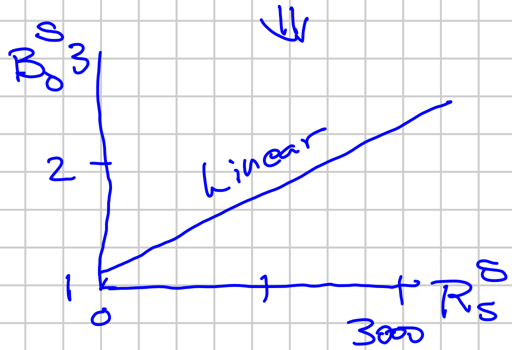


Solution GOR $R_s(p)$

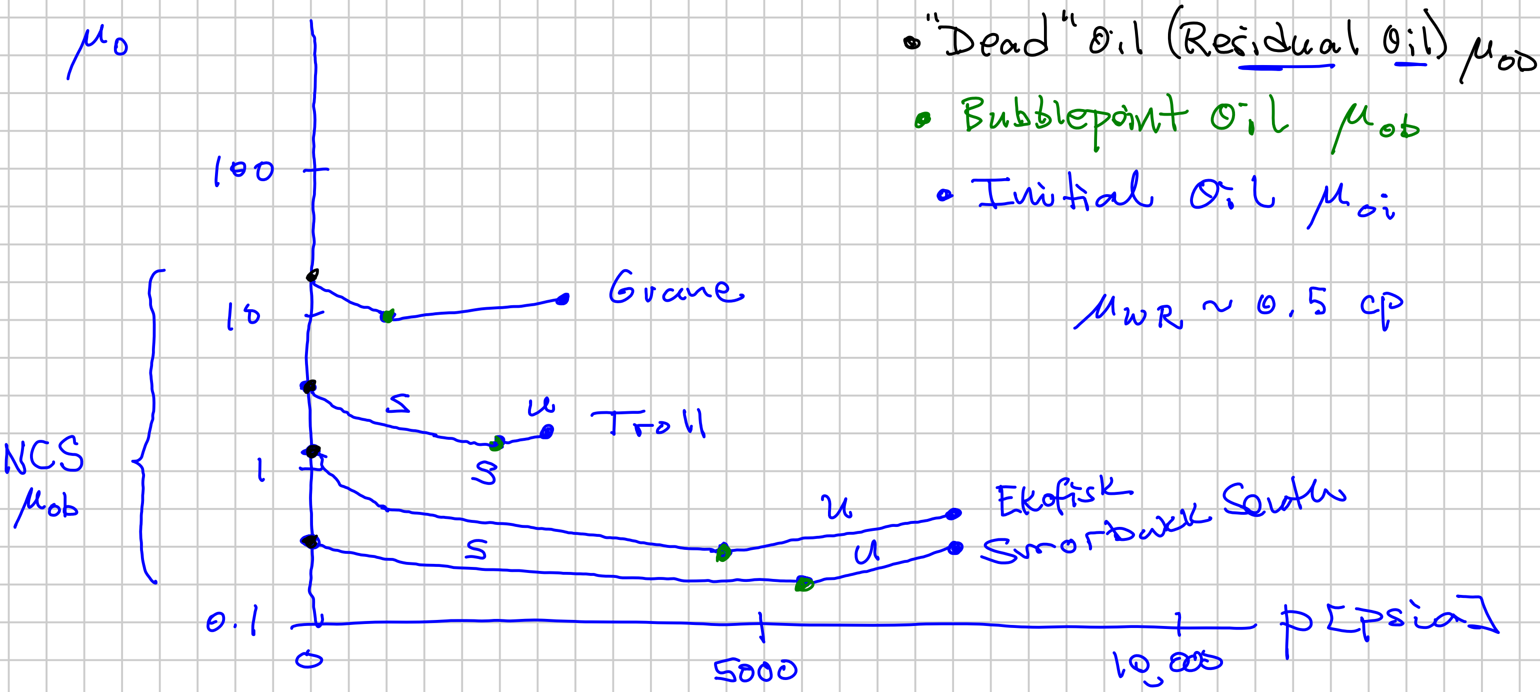


Shape "S" B_o = Shape "S" R_s

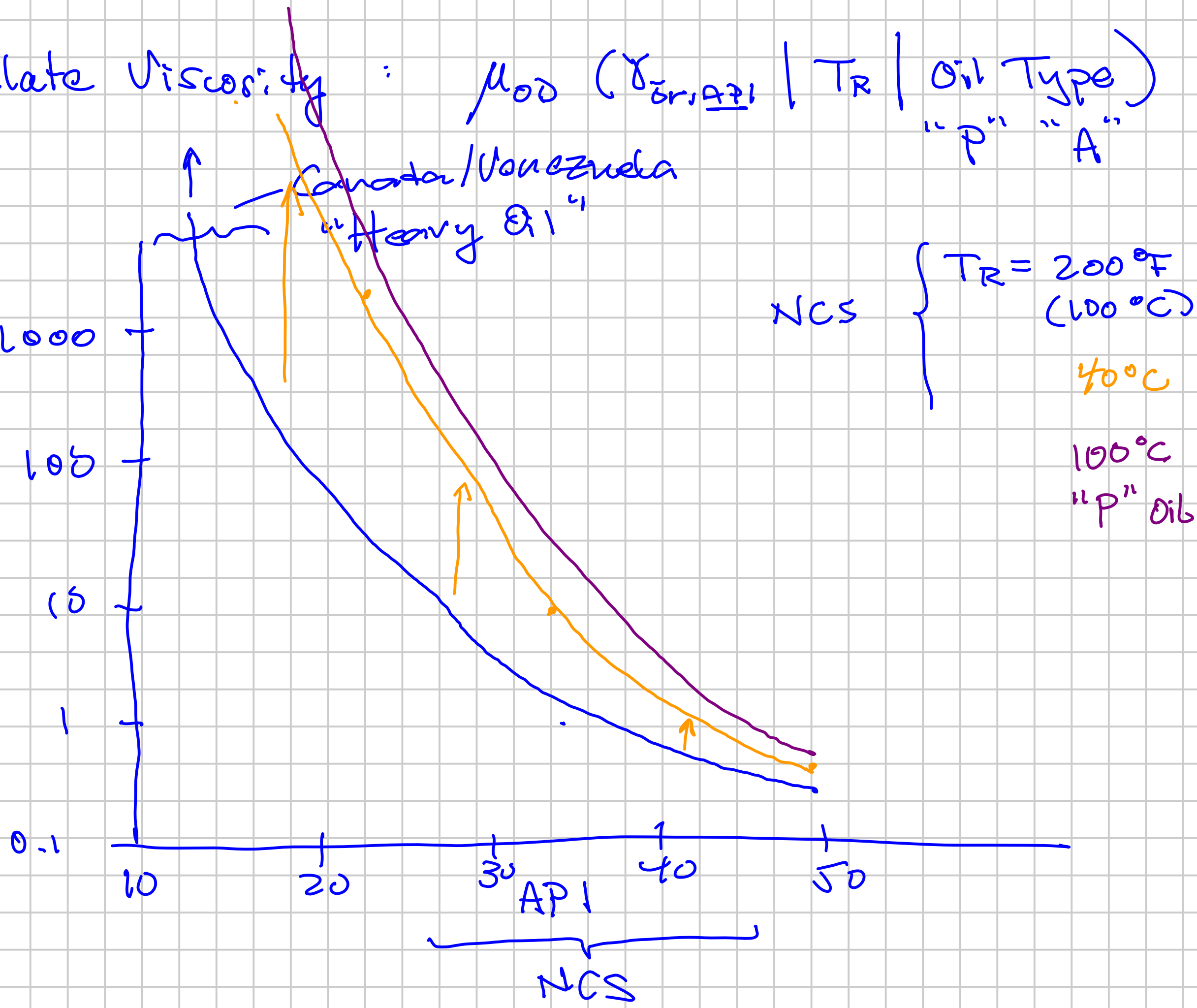
$\Downarrow$



Oil viscosity $\mu_o(p)$ | DLE (special, separate) test



Correlate Viscosity : μ_{oD} (γ_o, γ_{API} | T_R | Oil Type)
"P" "A"



$\Delta P_{\text{flow viscous}} \propto \mu$

$p<p_b$ μ_o increases due to gas being released

3.4.8 Bubblepoint-Oil Viscosity. The original approach by Chew and Connally[76] for correlating saturated-oil viscosity in terms of dead-oil viscosity and solution gas/oil ratio is still widely used.

$$\mu_{ob} = A_1(\mu_{oD})^{A_2}. \quad (3.123)$$

Fig. 3.22 shows the variation in μ_{ob} with μ_{oD} as a function of R_s. The functional relations for A_1 and A_2 reported by various authors differ somewhat, but most are best-fit equations of Chew and Connally's tabulated results.

Beggs and Robinson.[73]

$$A_1 = 10.715(R_s + 100)^{-0.515} \quad (3.124a)$$

and $$A_2 = 5.44(R_s + 150)^{-0.338}. \quad (3.124b)$$

Bergman.*

$$\ln A_1 = 4.768 - 0.8359 \ln(R_s + 300) \quad (3.125a)$$

and $$A_2 = 0.555 + \frac{133.5}{R_s + 300}. \quad (3.125b)$$

Standing.[3]

$$A_1 = 10^{-(7.4\times 10^{-4})R_s + (2.2\times 10^{-7})R_s^2} \quad (3.126a)$$

and $$A_2 = \frac{0.68}{10^{(8.62\times 10^{-5})R_s}} + \frac{0.25}{10^{(1.1\times 10^{-3})R_s}} + \frac{0.062}{10^{(3.74\times 10^{-3})R_s}}. \quad (3.126b)$$

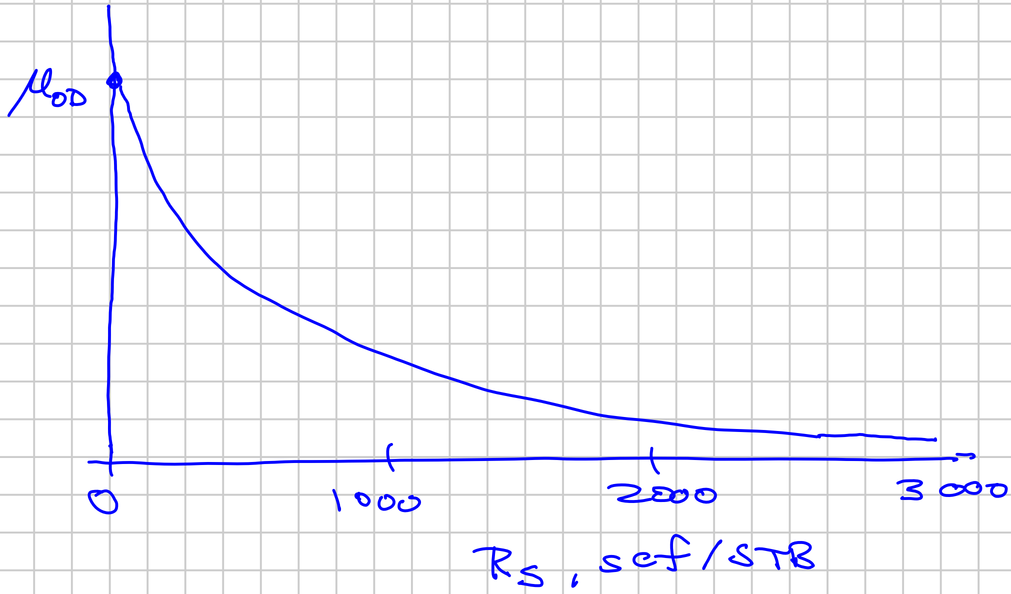
Aziz et al.[77]

$$A_1 = 0.20 + \left(0.80 \times 10^{-0.00081 R_s}\right) \quad (3.127a)$$

and $$A_2 = 0.43 + \left(0.57 \times 10^{-0.00072 R_s}\right). \quad (3.127b)$$

"S"

μ_{ob}



{ SEP, CCE, DLE }

	O			G	
p	B_o	R_s	μ_o	B_g	μ_g
p_{Ri} … p_b	CCE & SEP	SEP	DLE	Calc Z_g	Calc & Reported
… p_{min}					

Traditional

$r_s = 0$

Gas: Lab reports ($p < p_b$) Z_g : $B_g = \frac{p_{sc}}{T_{sc}} \cdot \frac{T_R}{p} Z_g$

Lab μ_g calc. from Lee-Gonzalez correlation

$\mu_g = f(\rho_g, T)$

The Lee-Gonzalez gas viscosity correlation (used by most PVT laboratories when reporting gas viscosities) is given by[44]

$$\mu_g = A_1 \times 10^{-4} \exp\left(A_2 \rho_g^{A_3}\right), \quad \ldots\ldots\ldots\ldots\ldots\ldots (3.65a)$$

$$\text{where } A_1 = \frac{(9.379 + 0.01607 M_g) T^{1.5}}{209.2 + 19.26 M_g + T},$$

$$A_2 = 3.448 + (986.4/T) + 0.01009 M_g,$$

$$\text{and } A_3 = 2.447 - 0.2224 A_2, \quad \ldots\ldots\ldots\ldots\ldots\ldots (3.65b)$$

with μ_g in cp, ρ_g in g/cm^3, and T in °R. McCain[19] indicates the accuracy of this correlation is 2 to 4% for $\gamma_g < 1.0$, with errors up to 20% for rich gas condensates with $\gamma_g > 1.5$.

"differential" (DLE test)

Converting DLE data (B_{od} & R_{sd}) + (SEP data) to $\underbrace{\text{"Engineering" } B_o \text{ \& } R_s}$ at $p < p_b$.

B_{ob}, R_{sb}

In books B_o R_s
- Reservoir Simulation
- Material Balance
- Rate Eqs (Reservoir & Pipe)
  IPR VLP

NEVER USE B_{od} & R_{sd} directly!!!

Conversion (valid for $R_{sb} \lesssim 1000$ scf/STB)

$$B_o(p<p_b) \cong B_{od}^{DLE}(p) \cdot \frac{B_{ob}^{SEP}}{B_{od,b}^{DLE}}$$

$$R_s(p<p_b) \cong R_{sb}^{SEP} - \left(R_{sd,b}^{DLE} - R_{sd}^{DLE}(p)\right) \frac{B_{ob}^{SEP}}{B_{od,b}^{DLE}}$$

DLE:

p	B_{od}	R_{sd}
p_b	$B_{od,b}$	$R_{sd,b}$
⋮		

SEP: B_{ob}, R_{sb}