DEPLETION PVT TESTS

Note Title 2013-10-03

OIL TEST: Differential Liberation (DLE) Experiment

Ch. 6 & App. D (DLE & SEP ⇒ "Traditional" Black-Oil PVT properties)

SEP: Multi-Stage Sep Test

B_o R_s "B_{gw}" ← wet gas FVF

Ch. 7 Black-Oil PVT Formulation

CVD: Gas Condensates & Volatile Oils ⇒ 1950s – 1980 • Traditional; >1980s • Modified

Whitson-Torp

DLE: Only used for Oils* (CCE Test ⇒ $p_s = p_b$)

* Always for oils with GOR $\lesssim$ 2000 scf/STB
2500
375–450 Sm^3/Sm^3

{ CVD alternative GOR $\gtrsim$ 400–500 Sm^3/Sm^3 }

Purpose: Properties of Oil & Gas Phases $= f(T_R, p \le p_b)$

→ ✓ρ_o ✓ρ_g (Z_g M_g or γ_g) ; V_o "Shrinkage" ✓ $\Delta V_o / V_o$

Does the depletion process **affect** ($\pm$ 1-2%)
- ρ's
- μ's
- ΔV's

→ No in most cases | "Some" for oils w/ GOR $\gtrsim 400\ Sm^3/Sm^3$

✓ $\left(\frac{\Delta V_g}{V_o}\right)$ released from the oil (dis-solution)

$\{y_i\}_{i \in C_3 - C_6}$ Gas Liquids

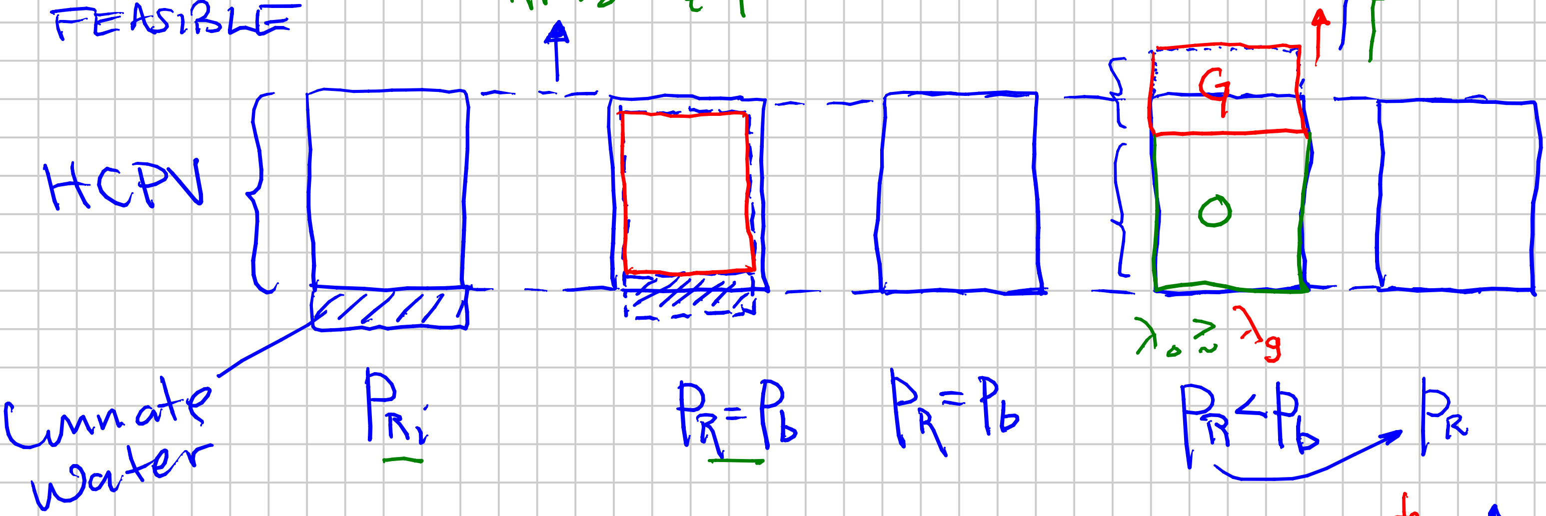
$\mu_o \quad \mu_g$

Option 1: Mimic actual Physical Depletion Process:

⇓

NOT FEASIBLE

RF % ~ $c_t \Delta p$



Flow Out from Reservoir

$$\lambda_g = \frac{k_g}{\mu_g} = \frac{k\, k_{rg}(S_g)}{\mu_g}$$

$$\lambda_o = \frac{k_o}{\mu_o} = \frac{k\, k_{ro}(S_o)}{\mu_o}$$

$$S_o = (1 - S_g) - S_w$$

$$k_{rp} \propto S_p^{\,n_p}$$

n_p ← 2.x – 4.x

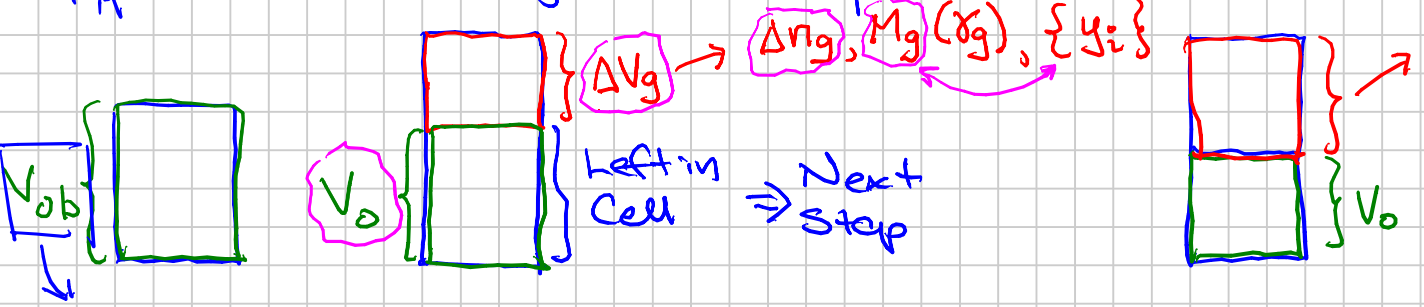
Option 2: (Actually Used)

Remove ALL Gas : Simplest Lab Procedure

Gives accurate measurement of ALL properties without a visual PVT cell.

Measured $\gamma_g = \frac{M_g}{M_{air}}$

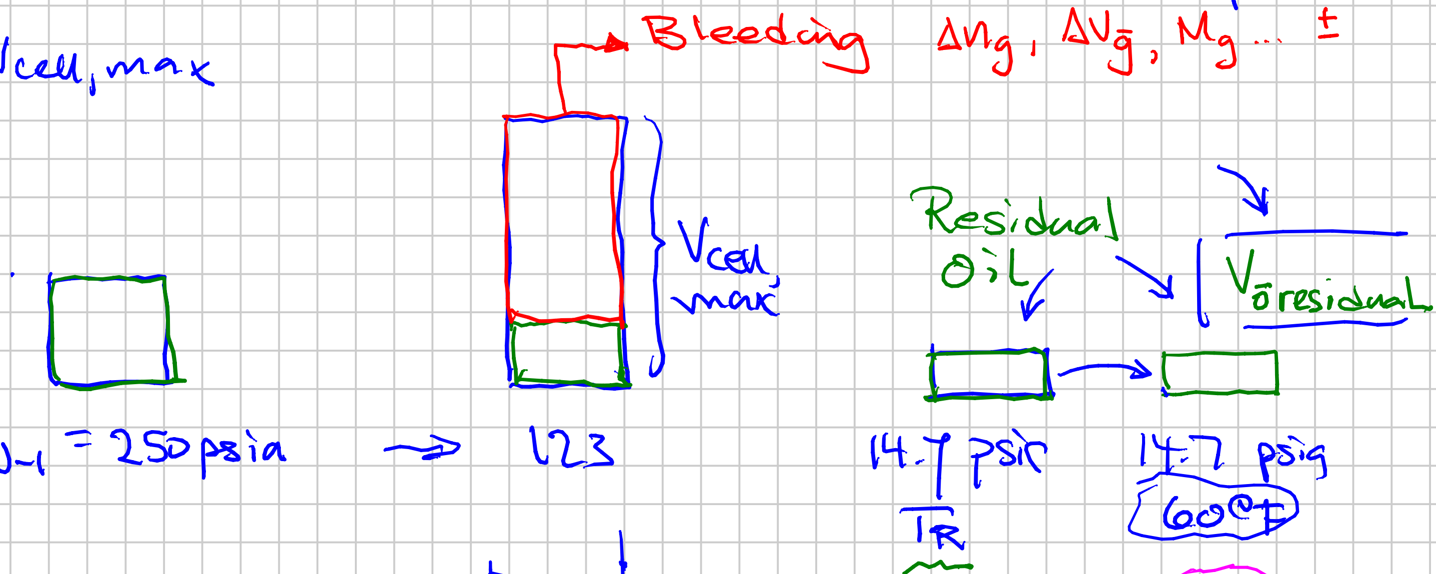
T_R = constant throughout the experiment

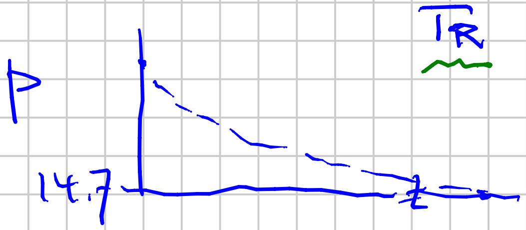


$p_1 = p_b$ $p_2 < p_1$ $p_3 < p_2$

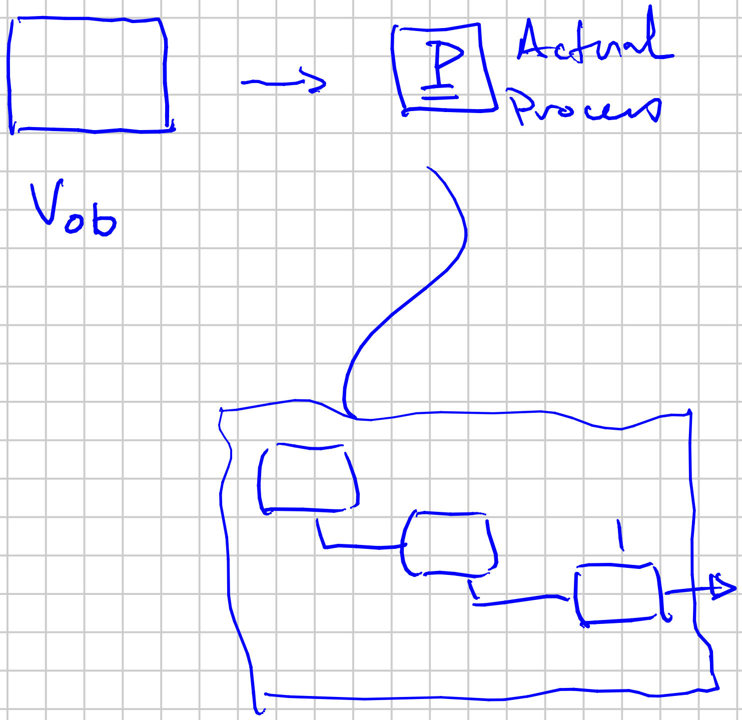
Next-to-Last Pressure (250 $^{450}_{150}$ psia) $\Delta V_g \propto \frac{\Delta n_g}{p}$

$V_{cell,max}$





Bleeding process is not really an equilibrium process ~ only approximate.



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

$V_{\bar{o}}$ STO $>$ $V_{\bar{o}\,residual}$

1% → 100%

5–20%

Lab Reports from DLE:

(1) $\dfrac{V_o(p)}{V_{\bar{o}\,residual}}$ "B_o" B_{od} NEVER to be used in engineering calculations with reservoir/prod/pipeline calculation

All text books

(2) Oil density: ρ_o

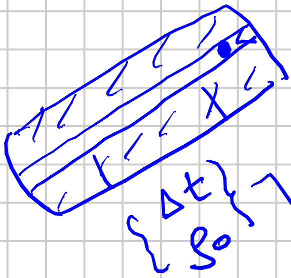
Calculated by a 'material balance'

±1-2%

$$\rho_o(p_j) = \frac{m_o(p_j)}{V_o(p_j)} = \frac{m_{\bar{o}\,residual} + \sum_{k=N}^{j+1} (\Delta n_{gk}) M_{gk}}{V_o(p_j)}$$

(3) Oil Viscosity $\mu_o (p < p_b)$ ← Maybe ≠ p_{DLE}

Lab runs a separate, parallel DL test to get oil viscosities:



@ T_R, $p \le p_b$

→ μ_o ± 5-15%

GAS:

Reported:

(4) $\Delta n_g \rightarrow \Delta V_{\bar{g}} \rightarrow \Delta R_{sd} = \frac{\Delta V_{\bar{g}}}{V_{\bar{o}residual}}$ and/or

"Solution" GOR

$$R_{sd}(p_j) = \frac{\sum_{k=N}^{j+1} \Delta V_{\bar{g}}}{V_{\bar{o}residual}}$$

Engineers "R_s" ≠ R_{sd}

DON'T USE DIRECTLY!

Important Quantity:

$$\underbrace{R_{sd}(p_b) - R_{sd}(p)}$$

Evolved Gas from $p_b \rightarrow p$

(5) $$Z_g = \frac{p \cdot \Delta V_g}{\Delta n_g R T_R}$$

⑥ M_g or γ_g each removed gas

{ ⑦ $\rho_g(p) = \dfrac{p\,M_g}{Z_g R T_R} = \dfrac{p \cdot M_g(p)}{Z_g(p)\, R\, T_R}$ }

$M_g(p)$ changes because $y_i(p)$

{ ⑧ $y_{DLE_i}(p)$ }

$B_{od} = \dfrac{V_o(p)}{V_{\bar{o}res.}(T_{sc})}$

@ T_R

$T_R \rightarrow T_{sc}$

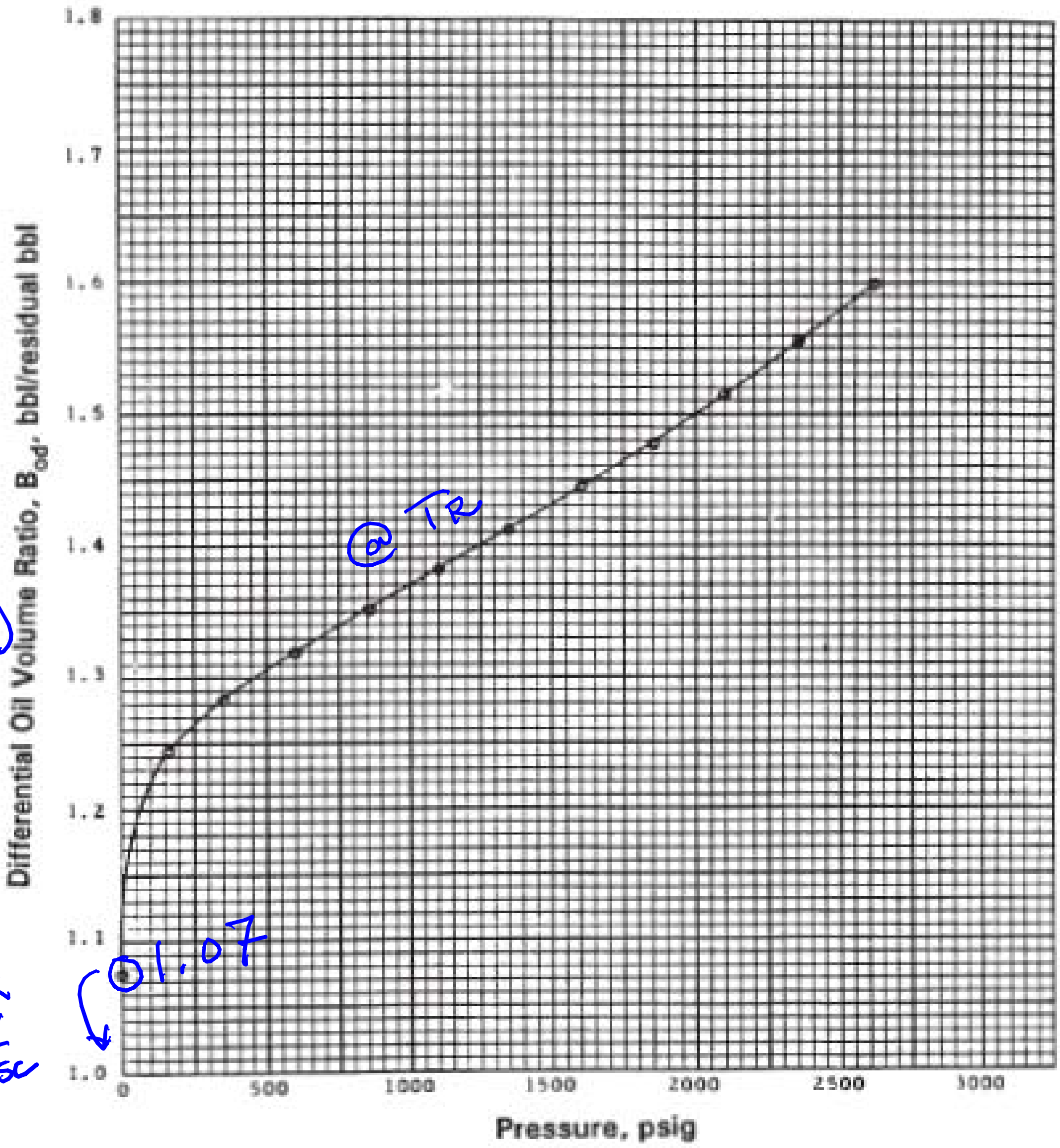


Fig. 6.7B—DLE data for an oil sample from Good Oil Co. Well 4; differential oil FVF (relative volume), B_{od}.

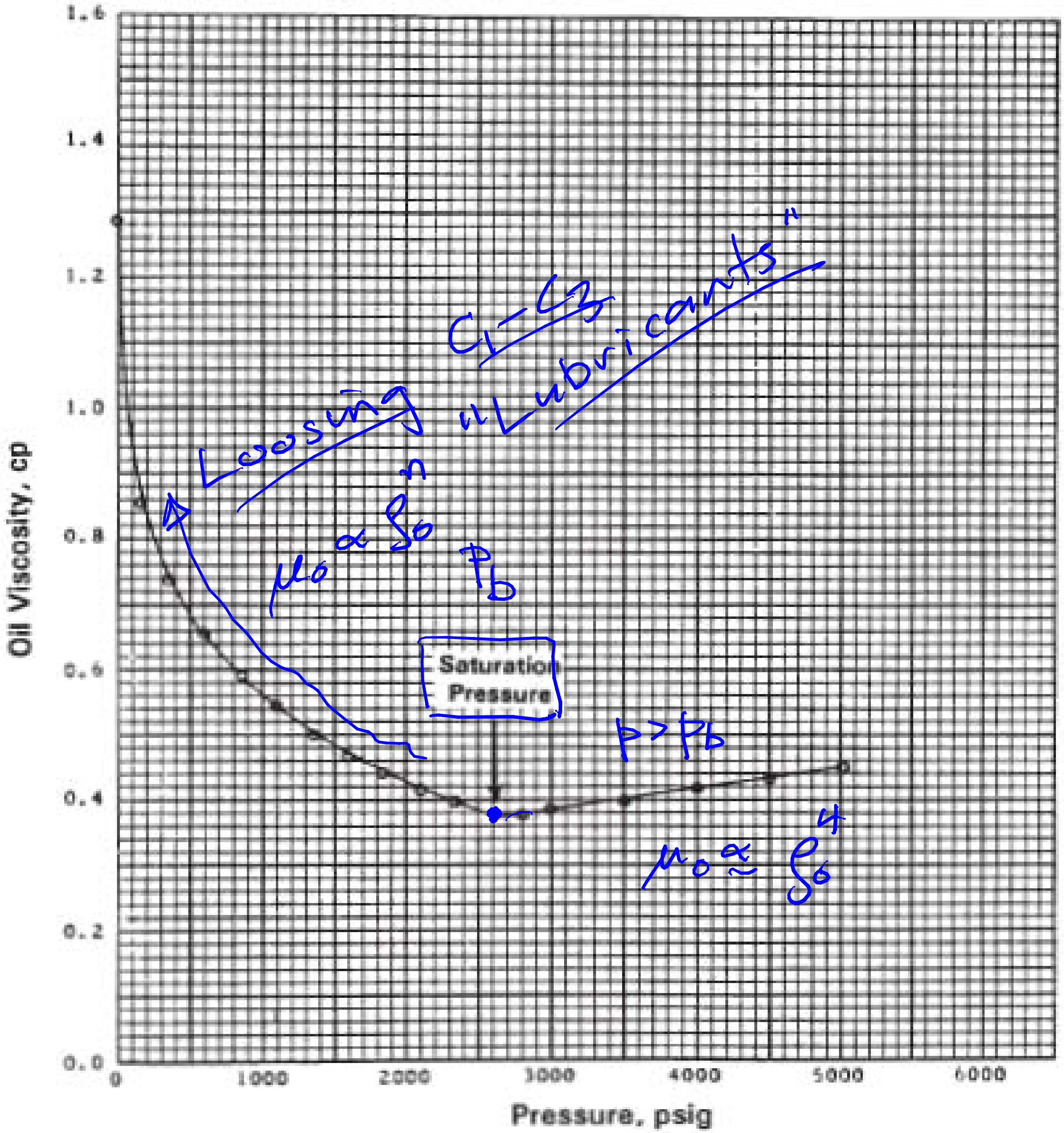


Fig. 6.7C—DLE data for an oil sample from Good Oil Co. Well 4; oil viscosity, μ_o.

CORE LAB

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

Differential Vaporization

Pressure (psig) p	Solution GOR (scf/bbl*) R_{sd}	Relative Oil Volume (RB/bbl*) B_{od}	Relative Total Volume (RB/bbl*) B_{td}	Oil Density (g/cm³) ρ_o	Deviation Factor Z Z_g	Wet Gas FVF (RB/bbl*) B_{gw}	Incremental Gas Gravity γ_g
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
→ @ 60°F		1.000**	?			?	

*Barrels of residual oil.
**At 60°F.

$$B_{td} = \frac{V_t}{V_{\bar{o}res}} = \frac{V_o + \left(\sum \Delta V_g\right)_{p_b \to p}}{V_{\bar{o}residual}}$$

(← @ p)

$$B_{gw} = \frac{V_g(p)}{V_{\bar{g}}}$$

assumption No surface condensation

$$\to B_{gw} = \frac{p_{sc}}{T_{sc}} \cdot \frac{T_R}{p} \cdot Z_g$$

$$\left(\sum_{p_b}^{p_j} \Delta V_g\right)_{@p} = \left[\sum_{k=2}^{j} \underbrace{\Delta n_{gk}(23.68)}_{\Delta V_{\bar{g}k}} \cdot \right] B_{gw}(p_j)$$

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

$\mu_g (p < p_b)$

Lee-Gonzalez

$\mu_g = f(\rho_g, T_R)$ Ch. 3

$\pm 5\%$