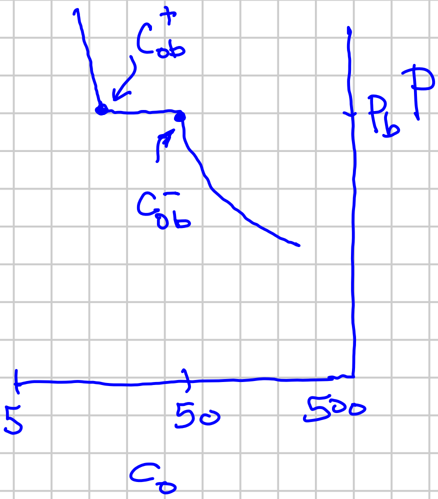
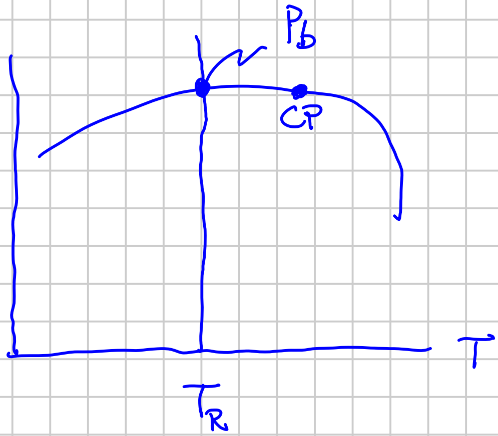
Note Title 2/27/2018

Isothermal Compressibility





Problem:
Henry Ramey
Hank

$$c_o \equiv -\frac{1}{V_o}\cdot\left(\frac{dV_o}{dp}\right)_T \approx \lim_{\Delta p \to 0} -\frac{1}{V_o}\frac{\Delta V_o}{\Delta p}$$

c_{ob} @ $p_b(T_r)$?

$$\Delta V_o = V_o(p) - V_o(p-\Delta p)$$

$$\Delta p = p$$

$$\left(\frac{k}{\phi \mu c}\right)$$

$\Delta p > 0$ $\quad p_b \to p_b + \Delta p > p_b$

Single Phase Oil ⇑ $\quad$ Single Phase Oil

} Conventional liquid compressibility $\sim 5\text{-}50 \cdot 10^{-6} \frac{1}{psi}$

$\Delta p < 0$ $\quad p_b \to \underbrace{p_b - \Delta p}_{\text{Two Phase}} < p_b$

small gas amount of the volume

$c_g \gg c_o$

$$B_g = \frac{p_{sc}}{T_{sc}} \frac{T_R Z_g}{p} \propto \frac{1}{p}$$

$b_g \propto p$ scf/ft^3 Sm^3/m^3

Initial Reservoir Gas Expansion Factor $b_{gi} \sim 50 - 300$

B_o

b_o = "shrinkage factor" 5% - 300%

b_{oi} = 0.95 0.33

B_{oi} = 1.05 3 - 3.5

$T_R \rightarrow T_{wh}$

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

Oil Formation Volume Factor "FVF" $T = T_R$

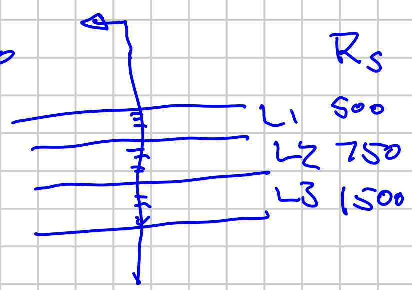
Oil Volume Factor @ any T

Gas-Oil Ratio GOR : R

Producing GOR : R_p property of a well

Solution GOR : R_s property of an oil

$R_p = 600$, 1200



Oil-Gas Ratio OGR : r

CGR r_p

r_s

Gas PVT Properties

Z_g (Z-factor) (Gas Deviation Factor)

$$pV = nRTZ_g$$

$$Z_g(T_{pr}, p_{pr}) \qquad T_{pr} \equiv \frac{T\,(^\circ R \text{ or } K)}{T_{pc}}$$

$$p_{pr} = \frac{p}{p_{pc}}$$

Getting $\underbrace{p_{pc} \text{ \& } T_{pc}}_{f(y_i,\, C_{7+})}$ key!

$\sim f(\gamma_g)$ — Reservoir Gas ⇒ use the reservoir gas MW_g to get γ_g

$$\rho_g = \frac{m}{V_g} = \frac{nM}{V_g} = \frac{pM_g}{RTZ_g}$$

Assume that producing wellstream ≃ reservoir gas:

$$\Downarrow$$

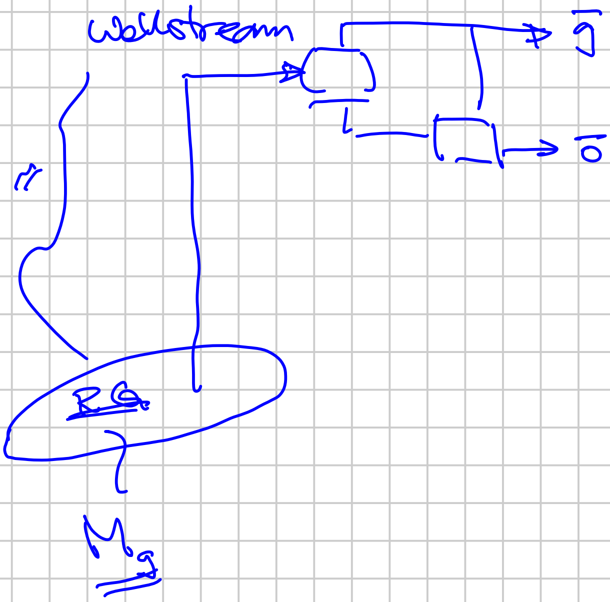
$$\underline{\gamma_w} = \frac{M_w}{M_{air}}$$

R depends on units $\left.\begin{matrix} p \\ T \\ m \\ V \end{matrix}\right\}$ App. A

Eq. 3.38

$$\frac{V_g(p,T)}{V_{\bar{g}}} = B_g = \frac{p_{sc}}{T_{sc}} \cdot \frac{TZ_g}{p}$$

Assumes that all of the gas at (p, T) becomes a surface gas – i.e., no surface oil condensing at surface



$\gamma_{\bar{g}}$

OGR, $r_p = \frac{V_{\bar{o}}}{V_{\bar{g}}}$

$\gamma_{\bar{o}}$, $M_{\bar{o}}$

$\gamma_w = \frac{M_g}{M_{air}}$

3.57 - 3.64 ignore for this course

Gas Viscosity: not measured
Lee-Gonalez:

$$\mu_g (T, \rho_g, M_g)$$

Ignore the other gas viscosity correlations in this course 3.66-3.68

Ignore Gas-O.I Total FVF (3.3.7)

Gas-PVT e-note: Ex-1.xls

Oil PVT Properties:

Many many correlations

$p_b = f(T, R_s, \gamma_o, \gamma_g)$ Standing

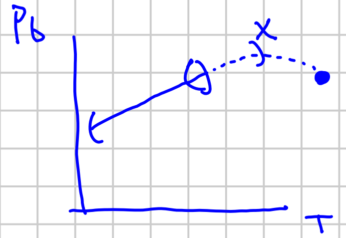
±2-20% accuracy

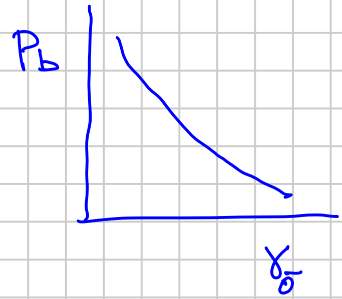
Glasø

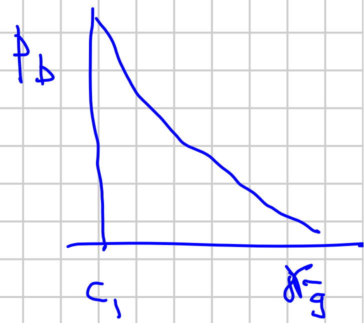
$R_s \lesssim 1500 \frac{scf}{STB}$

API ≳ 20

$T \lesssim 300°F$







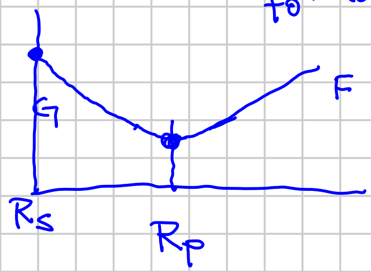
Appearance of Gas:

- Bad: $\lambda_o \downarrow$
- Good: Improved Oil Recovery by Gas Segregation
  Vertical Pipe Flow

$q_o = 1000 Sm^3/d$

$p_{wf} - p_{wh} \sim \Delta P_{tubing}$

friction gravity



MatBal —— " ——)

Prosper (Petroleum Experts)

Well Test SW

When we two phases anywhere (g+o)

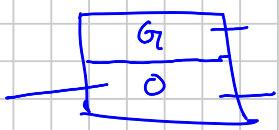
R T P

$\rho_{ob}(\underline{R_s}, \ldots$

$\mu_o(\underline{R_s}, \ldots$

" R_s "

@ (p,T)?



$p_d = p$ } @T

$p_b = p$

$(\underline{p}, T)_R$ T p

known exactly

Eq. 3.78

$p_b = f(R_s, T, \gamma_o, \gamma_g)$

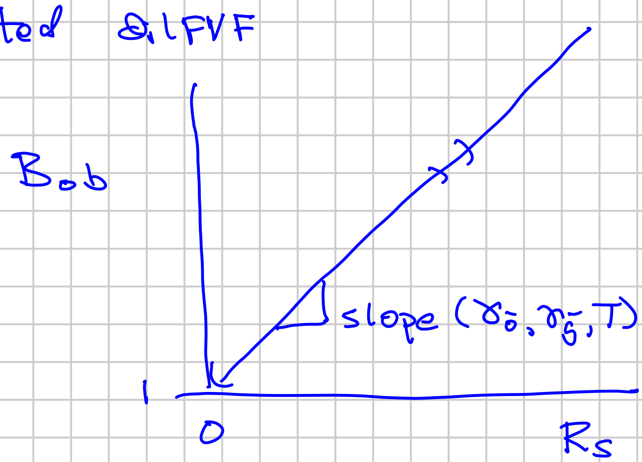
invert

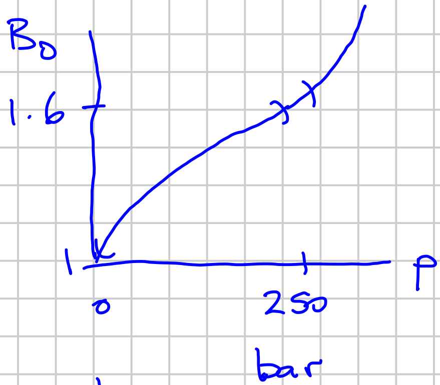
$R_s = f(p_b, T, \gamma_o, \gamma_g)$

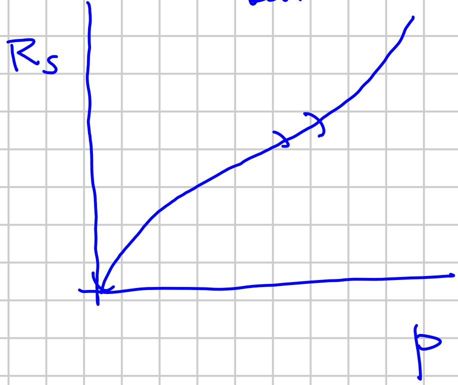
Eq. 3.87

B_{ob} : $f(R_s, \gamma_{\bar{o}}, \gamma_{\bar{g}}, T)$

Saturated Oil FVF



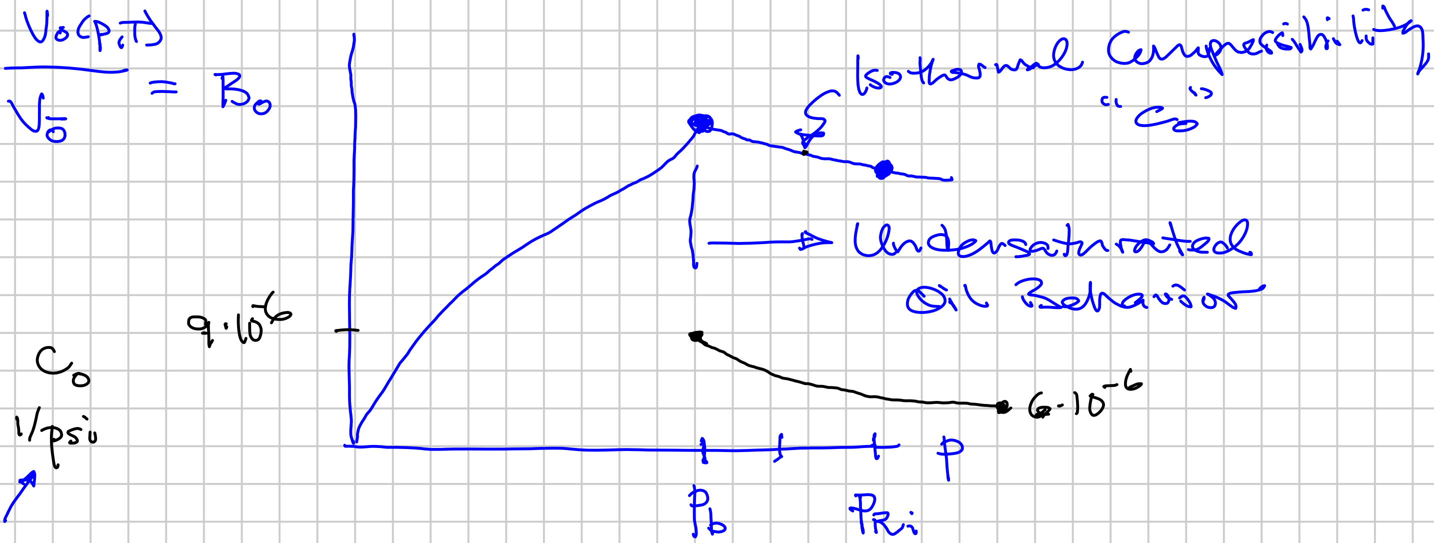




¿ $B_o(p > p_b)$

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

$R_s = 150$ sm³/sm³



$\frac{(vol)}{(vol)} \left(\frac{1}{psi}\right) = psi^{-1}$

bar^{-1}

1.22 kg/m³

$$\left[\rho_o^{(p,T)} = \frac{\rho_{\bar{o}} + R_s^{(p,T)} \gamma_{\bar{g}} \rho_{air,sc}}{B_o(p,T)}\right] \quad \frac{m_o}{V_o} = \frac{m_{\bar{o}} + m_{\bar{g}}}{V_o}$$

metric (SI)

Basis: $V_{\bar{o}} = 1$ sm³ $\qquad B_o = V_o / V_{\bar{o}} = V_o$

$m_{\bar{o}} = V_{\bar{o}} \cdot \rho_{\bar{o}} = \rho_{\bar{o}}$

$m_{\bar{g}} = V_{\bar{g}} \cdot \rho_{\bar{g}} \qquad V_{\bar{g}} = R_s \cdot \overset{=1}{V_{\bar{o}}} = R_s$

$\rho_{\bar{g}} = \rho_{air,sc} \cdot \gamma_{\bar{g}}$

= .

Gas Phase

$$\rho_g = \frac{p M_g}{R T Z_g}$$

Black-Oil PVT: B_g r_s

$$\left[\rho_g(p,T) = \frac{\rho_{\bar{g}} + \rho_{\bar{o}} r_s(p,T)}{B_g(p,T)} \right] = \frac{m_g}{V_g} = \frac{m_{\bar{g}} + m_{\bar{o}}}{V_g}$$

↑ "special" B_g

$\Rightarrow$ <u>not</u> $B_g = \frac{p_{sc}}{T_{sc}} \frac{T Z}{p}$

① μ_{ob}

& μ_o

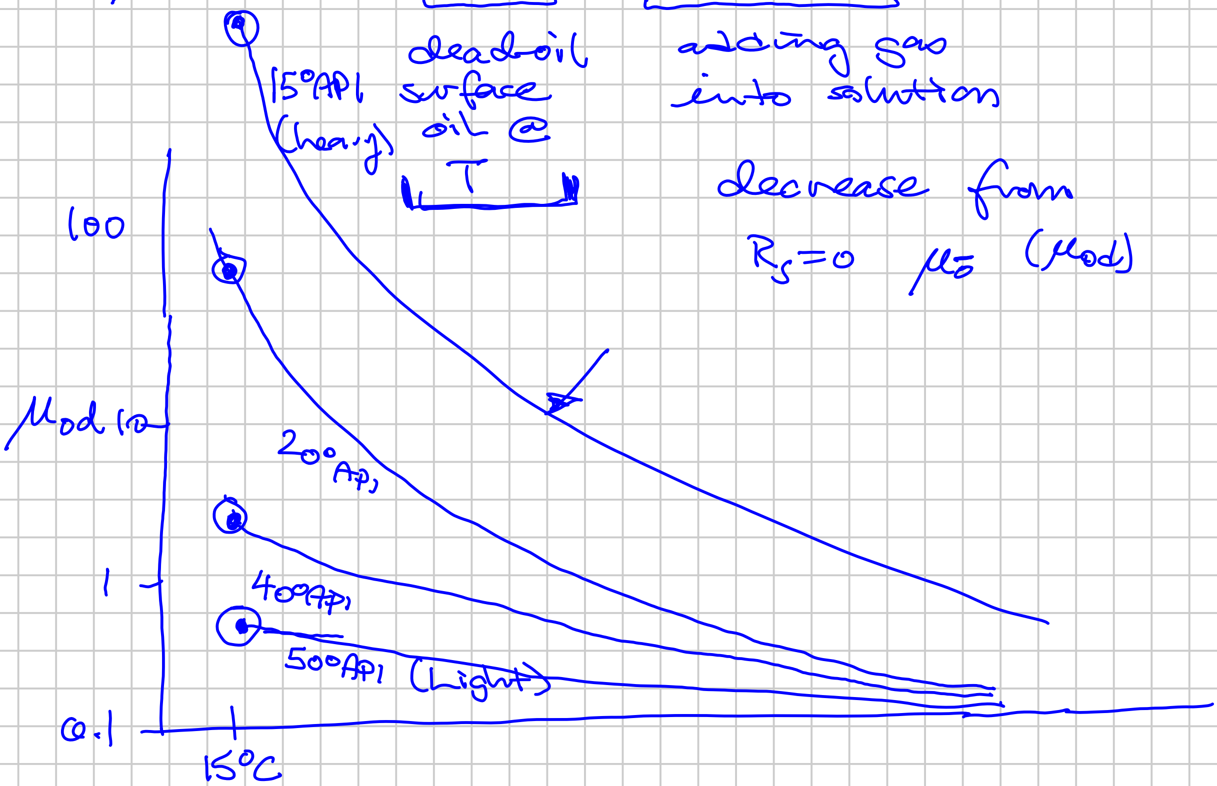
@ all pressures $p > p_b$

$$\mu_{ob}(T, p_b) = f\left(\underbrace{\mu_o(T)}_{\mu_{od}(T)},\ \underbrace{R_s(T, p_b)}\right)$$

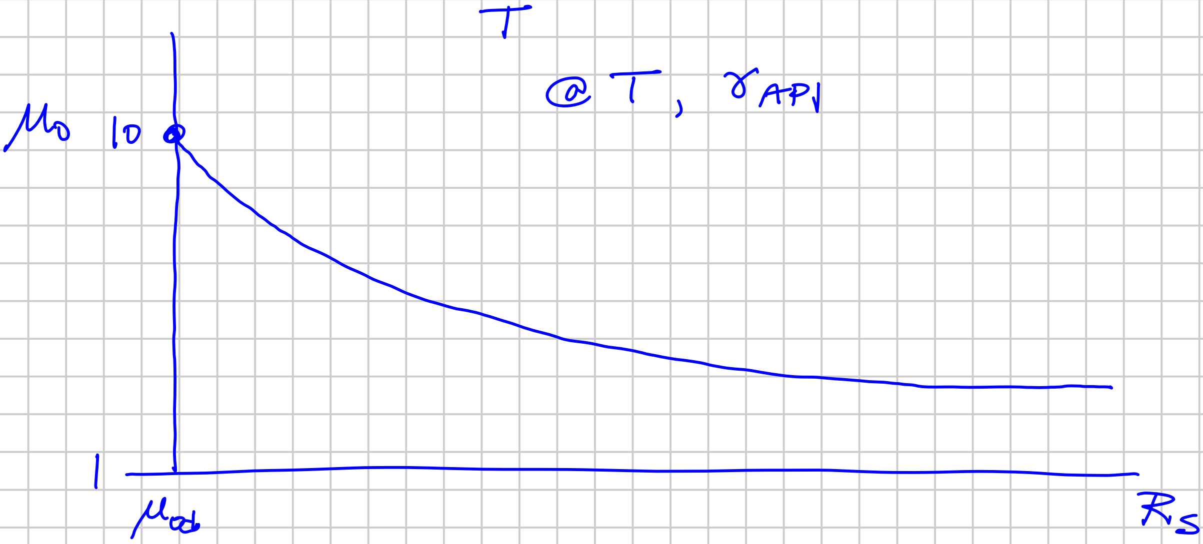
$\mu_o(T)$: dead oil, surface oil @ T

$R_s(T, p_b)$: adding gas into solution

decrease from $R_s = 0$ μ_o (μ_{od})



@ T, γ_{API}



μ_{oi} @ T_R	
0.1 cp ⋮ 10 cp	North Sea
10,000 cp	Venezuela Canada