Note Title 3/3/2016

BLACK-OIL PVT (T = constant)

OIL PHASE

p | R_s | B_o | μ_o

$p_{max} = p_{bi}$ $\quad p \le p_{bi}$ (R_{si})

SATURATED

"x_{vi}" "x_i"

- $p = p_b$
- $R_s(p)$

$B_o(p)$ } $B_o \propto R_s$

$\mu_o(p)$

- B_o & μ_o change because of p & R_s

GAS PHASE

p | r_s | B_{gd} | μ_g

$p \le p_{di}$ (r_{si})

$p = p_d$

$r_s(p)$

$B_{gd}(p)$

UNDERSATURATED

R_s specified

p_b from $R_s(p)$ Saturated Curve

$p > p_b(R_s)$

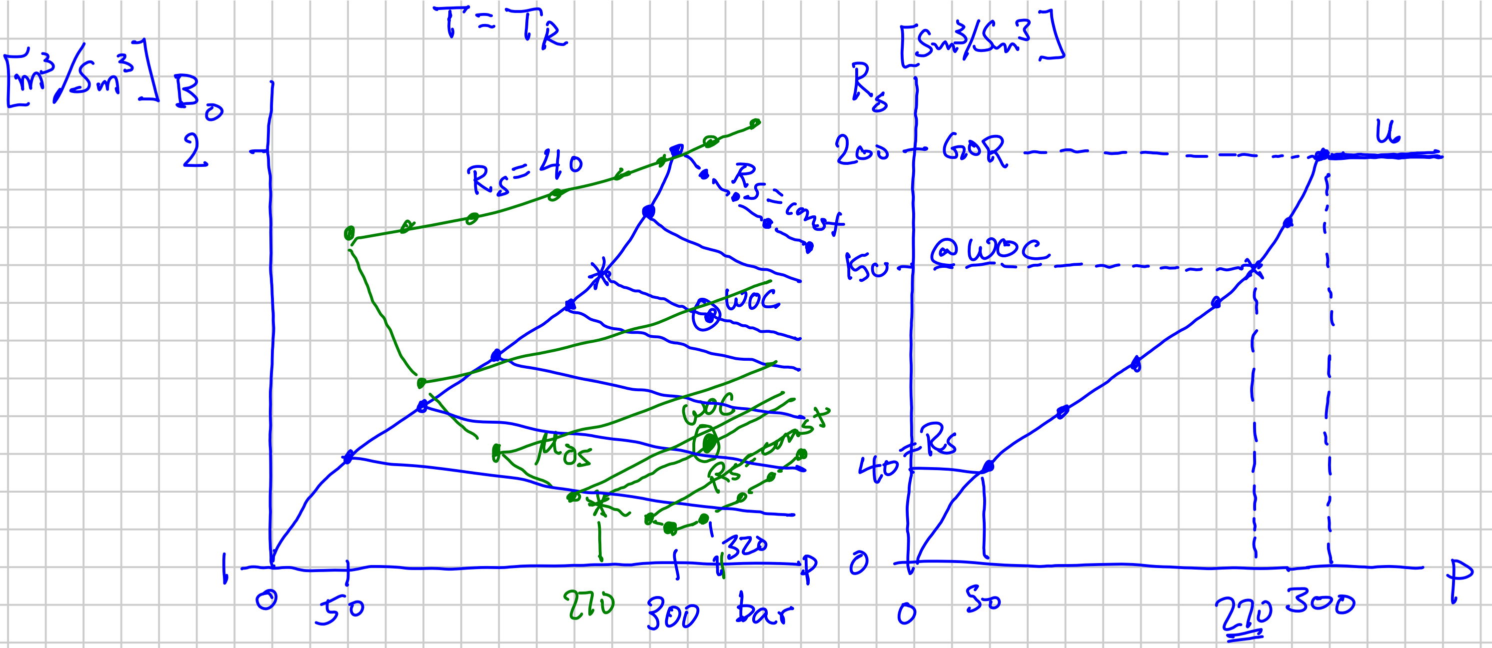
$B_o(p>p_b)$ & $\mu_o(p>p_b)$

change only because of pressure change

Constants

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

Sat & Undersat



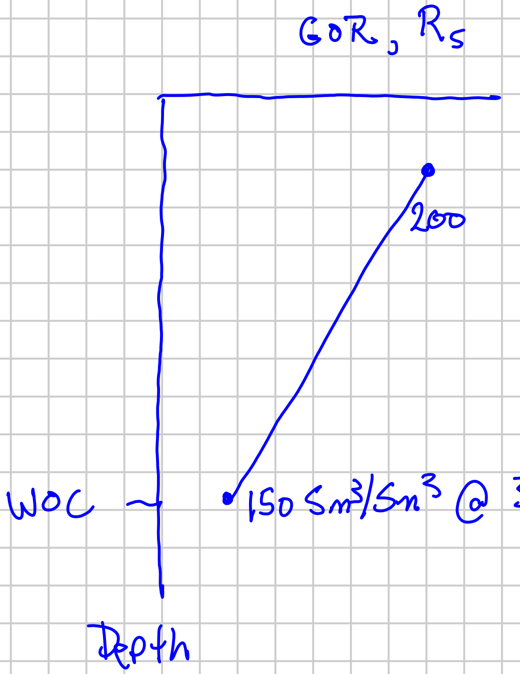
Somewhere in our "system" (@ T_R) we have $GOR = 200\ Sm^3/Sm^3$

$p_b(R_s = GOR = 200) = 300$ bara

p_R where our system is 320 bara – e.g. at WOC (Water-Oil Contact)

$p > p_b \Rightarrow$ Undersaturated

Many reservoirs have an initial vertical variation of R_s vs Depth (TVD)



150 Sm^3/Sm^3 @ 320 bar $\Rightarrow$ $p_b = 270$ bara from $R_s(p)$ curve

Sometimes we use the concept of a "SURFACE WET GAS WELLSTREAM"

$V_{\bar{g}w} = V_{\bar{g}g} + V_{\bar{o}g}\left(\frac{\rho_{\bar{o}}}{M_{\bar{o}}}\right)\cdot\left(\frac{RT_{sc}}{p_{sc}}\right)$

Gas PVT Properties

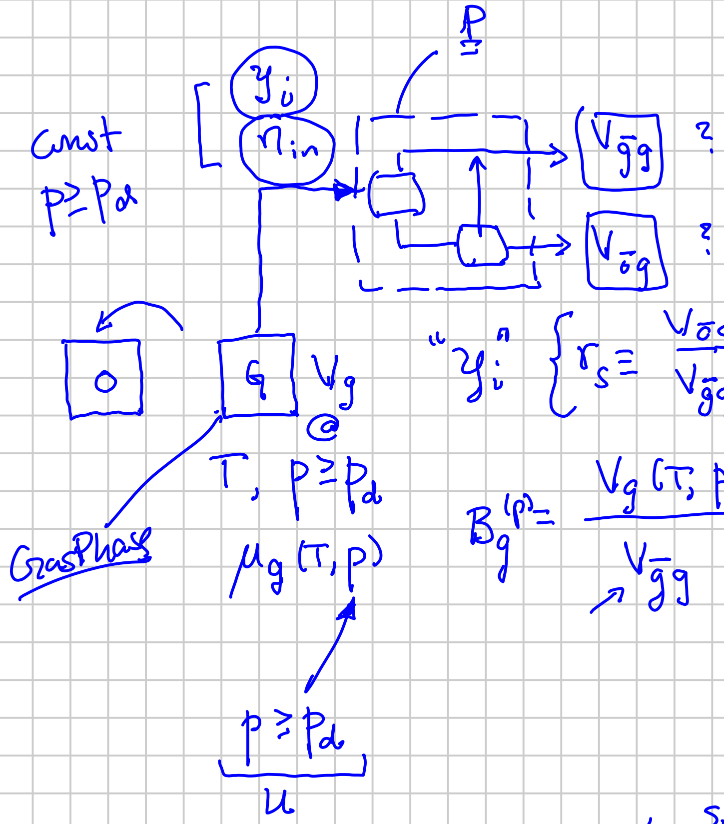
p $\quad r_s \quad B_g \quad \mu_g$

Sat Table | Undersat. Table

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

$y_i \Rightarrow : r_s$

$y_i \;\&\; n \quad \Rightarrow : V_{\bar{o}g},\ V_{\bar{g}g}$



"y_i": $\left\{ r_s \equiv \frac{V_{\bar{o}g}}{V_{\bar{g}g}} \right.$

$$B_g(p) = \frac{V_g(T, p)}{V_{\bar{g}g}}$$

Taking a saturated gas to an undersaturated state:

$V_d = 100$ cc	$p_d = 300$ bara	$r_s = 500 \cdot 10^{-6}\ \frac{Sm^3}{Sm^3}$
$V = 60$ cc	$p = 500$ bara	$r_s =$ — " —

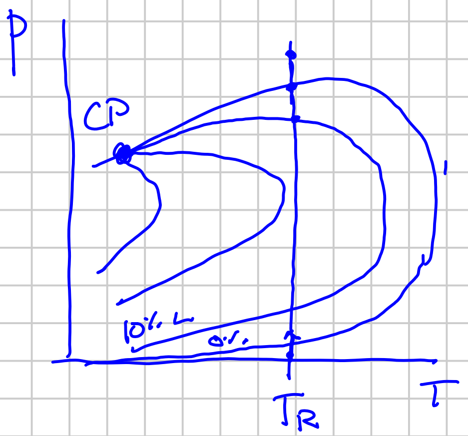
y_i constant

n constant

Gas FVF : B_g

"wet"

Traditional $\quad B_{gw} = \frac{p_{sc}}{T_{sc}} \cdot \frac{T_R Z_g}{p} = \frac{V_g(p, T)}{V_{\bar{g}w}}$



99% of all petroleum literature

$\Rightarrow$ Assumes $r_s = 0 \quad (V_{\bar{o}g} = 0)$

DON'T usually want to use this definition

$$\underbrace{B_{gd}}_{\text{USE}} \equiv \frac{V_g(p, T)}{V_{\bar{g}g}} = \underbrace{\frac{p_{sc}}{T_{sc}} \cdot \frac{T_R Z_g}{p}}_{\text{Traditional}} \cdot \underbrace{\left(\frac{n_g}{n_{\bar{g}g}}\right)}_{\geq 1} \geq B_{gw}$$

$V_{\bar{g}g} \leftarrow$ surface gas product we sell

Dry Gas FVF

We have "dried" the (reservoir) gas @ p, T by the surface process & to "surface" (dry) sales gas

$$\frac{n_{\bar{g}g}}{n_g} \sim 0.99^{(1)} \rightarrow 0.85^{(-)}$$

$$\simeq (1 - y_{6+})$$

↑ In the gas phase (p, T)

boe = barrel oil equivalent [Energy Equivalence]

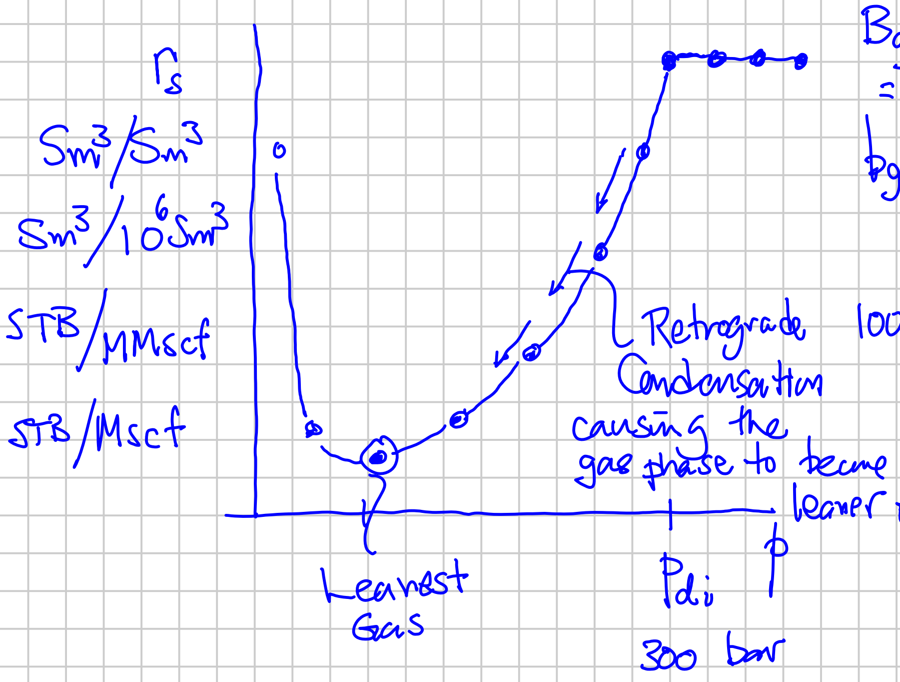
1 STB ~ 6000 scf

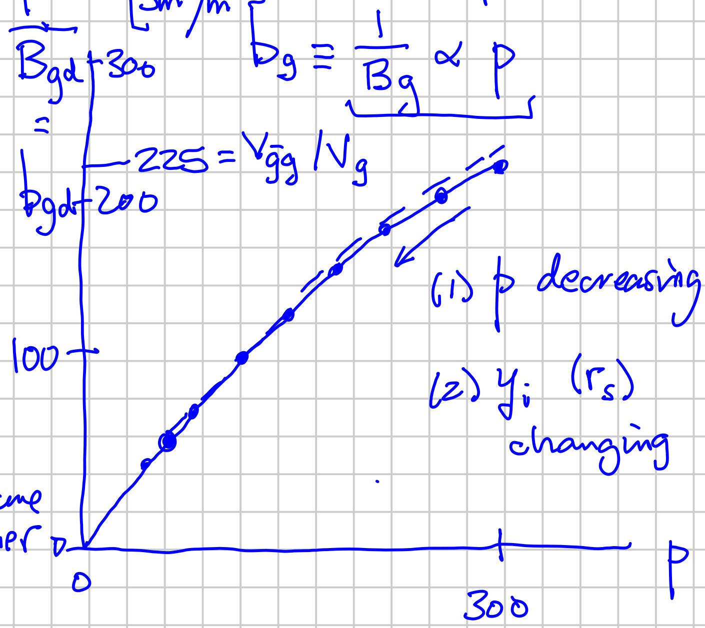
$$900 \cdot 10^{12} \text{ scf} = 900 \cdot 10^{9} \text{ Mscf} \times \frac{1 \text{ STB}}{6 \text{ Mscf}} = 150 \cdot 10^{9} \text{ STB}$$

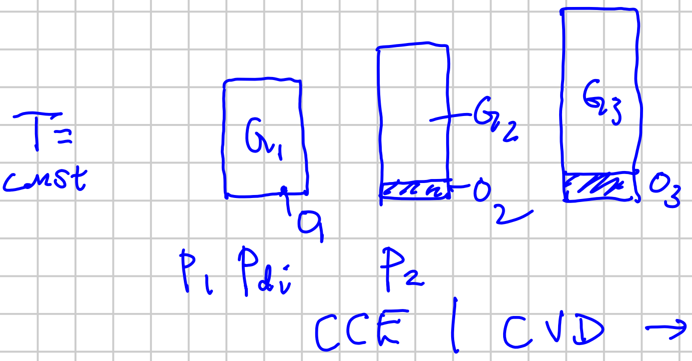
Saturated Gas Phase BO PVT

$B_g \propto \frac{1}{p}$

$b_g = \frac{1}{B_g} \propto p$







$$b_{gd} = \frac{T_{sc}}{p_{sc}} \cdot \frac{p}{T Z_g} \cdot \left(\frac{n_{\bar{g}g}}{n_g}\right)$$

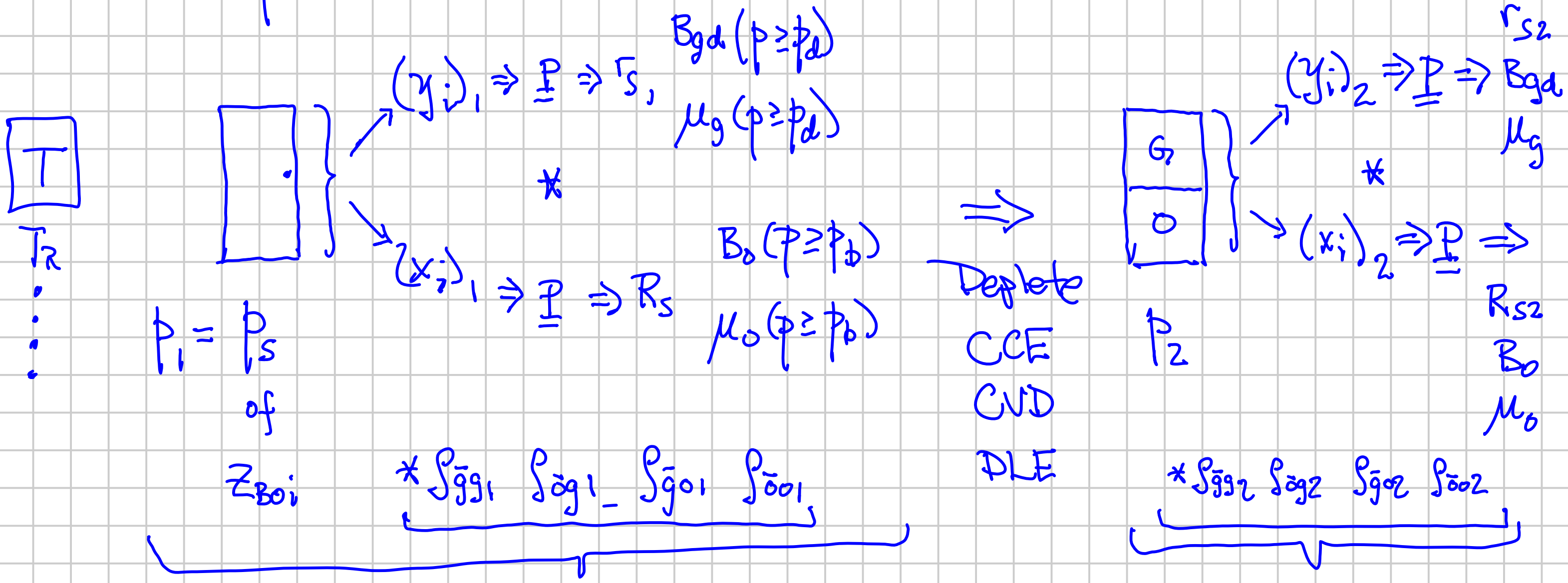
$Z_g(p, T, y)$ ← $y(r_s)$

$\frac{n_{\bar{g}g}}{n_g}$ (r_s)

Saturated	undersat.
$\mu_g(p, r_s)$	$\mu_g(p, r_s = const)$
(p, y)	$p \geq p_d$

How to create the saturated Gases and Saturated Oils?

- Start with a sample, composition z_{BOi}
- Fix temperature
- Deplete, lower the p in stages ⇒ gives 2-phase G–O equilibrium



BO PVT : Saturate $p_{s1} = p_1 = p_{b1} = p_{d1}$

Undersaturated $p > p_{s1}$

Sat. BOPVT @ p_{s2}

Undersat BOPVT $p > p_{s2}$

repeat down to a low pressure $p_N \sim 1$ atm

Regarding the phase densities:

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

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

Assume single $\rho_{\bar{o}}$, & single $\rho_{\bar{g}}$ ⇒ Can lead to inaccuracies in ρ_g & ρ_o

"Pick" the $\rho_{\bar{o}}$ & $\rho_{\bar{g}}$ so that you get the best $\rho_o(T,p)$ & $\rho_g(T,p)$ Where it is most important

Experience factor
and/or
Numerical Experimentation

errors 0.x% → 5%