Comments on Sec. 7.4.3 of Phase Behavior Monograph regarding "MBO" SGD material balance by Gunnar Borthne.

$V_b = 1$ bbl

$V_p = \phi$

$V_{HCPV} = \phi(1-S_w) = V_{oR} + V_{gR}$

The surface product volumes ($V_{\bar{o}}$ and $V_{\bar{g}}$) distributed between the two reservoir HC phases (S_o and S_g) are given by (@ any time):

$$A_o = N_R = V_{\bar{o}} = \phi\Big[\underbrace{\frac{S_o}{B_o}}_{V_{\bar{o}o}} + \underbrace{\frac{S_g}{B_{gd}} r_s}_{V_{\bar{o}g}}\Big] = N - N_p$$

$$A_g = G_R = V_{\bar{g}} = \phi\Big[\underbrace{\frac{S_o}{B_o} R_s}_{V_{\bar{g}o}} + \underbrace{\frac{S_g}{B_{gd}}}_{V_{\bar{g}g}}\Big] = G - G_p$$

Current in-place surface volumes

~~after~~

$N_R = N$ @ $p_R = p_{Ri}$

$G_R = G$ @ $p_R = p_{Ri}$

Differential change in surface product volumes during a small pressure drop $p_{Rk-1} \to p_{Rk}$:

$$A_{ok-1} - A_{ok} = N_{Rk-1} - N_{Rk} = \Delta N_{pk}$$

$$A_{gk-1} - A_{gk} = G_{Rk-1} - G_{Rk} = \Delta G_{pk}$$

Instantaneous Producing GOR Average over $k-1 \to k$ period:

$$\bar{R}_{pk} = \frac{\Delta G_{pk}}{\Delta N_{pk}} = \frac{\frac{1}{2}(E_{gk-1} + E_{gk})}{\frac{1}{2}(E_{ok-1} + E_{ok})} \quad ; \quad R_p = \frac{E_g}{E_o}$$

$$\bar{R}_{pk} = \frac{1}{2}(R_{pk-1} + R_{pk}) = \frac{1}{2}\left(\frac{E_{gk-1}}{E_{ok-1}} + \frac{E_{gk}}{E_{ok}}\right)$$

<prove these give the same result>

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Oil Saturation Equation

$$\phi\left[\frac{S_o}{B_o} + \frac{S_g}{B_{gd}} r_s\right] = N - N_p$$

$$N = \phi(1-S_w)/B_{oi}$$

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

$$\frac{\phi\left[\frac{S_o}{B_o} + \frac{(1-S_w)-S_o}{B_{gd}} r_s\right]}{\phi(1-S_w)/B_{oi}} = \frac{N-N_p}{N}$$

$$\frac{S_o}{(1-S_w)}\left(\frac{B_{oi}}{B_o} - \frac{r_s}{B_{gd}}B_{oi}\right) + \frac{r_s}{B_{gd}}B_{oi} = 1 - \frac{N_p}{N}$$

$$S_o = (1-S_w)\left[\frac{\left(1-\frac{N_p}{N}\right) - \frac{r_s}{B_{gd}}B_{oi}}{\frac{B_{oi}}{B_o} - \frac{r_s}{B_{gd}}B_{oi}}\right]\cdot\frac{B_o B_{gd}}{B_o B_{gd}}$$

$$\boxed{S_o = (1-S_w)\left[\frac{\left(1-\frac{N_p}{N}\right)B_o B_{gd} - r_s B_o B_{oi}}{B_{oi}(B_{gd} - r_s B_o)}\right]}$$

Walsh Eq. 2

< What is the range of S_o? Can be < 0? Can be $> 1-S_w$? >

< Derive similar relation if Initially only Reservoir gas condensate: $S_o = 0$, $S_g = 1-S_w$ @ $P_R = P_{Ri}$ >

< Derive general relation if Initially containing Reservoir Gas & Reservoir Oil: $S_o > 0$, $S_g > 0$ @ $P_R = P_{Ri}$ >

$$N = \left[\frac{S_{oi}}{B_{oi}} + \frac{S_{gi}}{B_{gdi}} r_{si}\right]\phi$$

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Producing Gas-Oil Ratio Equation

$$R_p = \frac{q_{\bar g}}{q_{\bar o}} = \frac{q_{\bar g g} + q_{\bar g o}}{q_{\bar o o} + q_{\bar o g}}$$

$$R_s = \frac{q_{\bar g o}}{q_{\bar o o}} \quad , \quad r_s = \frac{q_{\bar o g}}{q_{\bar g g}}$$

$$q_{\bar g o} = R_s\, q_{\bar o o} \quad , \quad q_{\bar o g} = r_s\, q_{\bar g g}$$

$$R_p = \frac{q_{\bar g g} + R_s\, q_{\bar o o}}{q_{\bar o o} + r_s\, q_{\bar g g}}$$

$$q_{gR} = q_{\bar g g} B_{gd} = C \int_{p_{wf}}^{p_R} \frac{k_{rg}}{\mu_g B_{gd}}\, dp \simeq C \overbrace{\left(\overline{\frac{k_{rg}}{\mu_g B_{gd}}}\right)}^{\bar\lambda_{\bar g}} (p_R - p_{wf})$$

$$q_{oR} = q_{\bar o o} B_o = C \int_{p_{wf}}^{p_R} \frac{k_{ro}}{\mu_o B_o}\, dp \simeq C \underbrace{\left(\overline{\frac{k_{ro}}{\mu_o B_o}}\right)}_{\bar\lambda_{\bar o}} (p_R - p_{wf})$$

<What are the "correct" averages of surface product mobilities $\bar\lambda_{\bar g}$ and $\bar\lambda_{\bar o}$? >

$$R_p = \frac{\cancel{C} \bar\lambda_{\bar g} \Delta p + \cancel{C\Delta p}\, \bar\lambda_{\bar o} R_s}{\cancel{C\Delta p}\, \bar\lambda_o + \cancel{C\Delta p}\, \bar\lambda_{\bar g} r_s} \cdot \frac{\frac{1}{\bar\lambda_{\bar o}}}{\frac{1}{\bar\lambda_{\bar o}}}$$

$$R_p = \frac{(\bar\lambda_{\bar g}/\bar\lambda_{\bar o}) + R_s}{1 + (\bar\lambda_{\bar g}/\bar\lambda_{\bar o})}$$

Borthne nomenclature

$$R_p = \frac{\left[\frac{k_{rg}}{k_{ro}}\left(\frac{\mu_o B_o}{\mu_g B_{gd}}\right) + R_s\right]}{\left[1 + \frac{k_{rg}}{k_{ro}}\left(\frac{\mu_o B_o}{\mu_g B_{gd}}\right) r_s\right]} = \frac{[E_g]}{[E_o]} = \frac{\Delta G_p}{\Delta N_p}$$

chw

$\frac{k_{rg}}{k_{ro}}(p)$ Equation

$$\frac{k_{rg}}{k_{ro}} = f(R_p \, ; \, PVT(p))$$

$$\frac{k_{rg}}{k_{ro}}(p) = \frac{\mu_g B_{gd}}{\mu_o B_o} \left(\frac{R_p - R_s}{1 - r_s R_p} \right)$$

where $\mu(p)$, $B(p)$, $R_s(p)$ & $r_s(p)$

The R_p eq. and the k_{rg}/k_{ro} eq. are only valid in the reservoir where "steady state" flow exists, meaning that the flowing mixture has a GOR = R_p.

- For SGD oil reservoirs, Muskat shows that the SS flow assumption is valid throughout the drainage volume $r_w < r < r_e$.
- For Gas Condensates, Fevang (and Whitson) show that the SS flow assumption is only valid from $p_{wf} < p < p^*$ where $p^* = p_d$ of the produced wellstream.

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