"VOLUMETRIC" GAS MATERIAL BALANCE: $\bar{p}_R(G_p)$

Note Title 4/10/2018

Gas-MB-Fetkovich-Reese-Whitson.pdf *

Gas-Well-Deliverability-Fetkovich.pdf

$\bar{p}_R$ = Vol. Avg. Res. Pressure

G_p = cum. surface gas volume produced

Volumetric M.B.
↓
Surface Products ("components" in black-oil PVT formulation)

$V_{\bar{g}}$	scf	Sm³
$V_{\bar{o}}$	STB	Sm³
$V_{\bar{w}}$	STB	Sm³

Time 0:

IGIP (G) = initial $\bar{g}$ in place

IOIP (N) = initial $\bar{o}$ in place

IWIP (W) = initial $\bar{w}$ in place

$$V_{\bar{o}i} = V_{\bar{o}p} + (V_{\bar{o}R} - \overset{\text{no}}{V_{\bar{o}inj}})$$

$$\underset{STB}{N} = N_p + N_R = \underset{STB}{N_o} + \underset{STB}{N_g}$$

$$V_{\bar{g}i} = V_{\bar{g}p} + V_{\bar{g}R}$$

$$* \quad G = G_p + (G_R - G_{inj}) = G_o + G_g$$

$$V_{\bar{w}i} = V_{\bar{w}p} + V_{\bar{w}R}$$

$$* \quad W = W_p + (W_R - W_{inj})$$

Surface Product Volume Balance

Ekofisk : $N_o \sim 6 \cdot 10^9$ STB, $R_{si} \sim 1500$ scf/STB } $G_o = 9 \cdot 10^{12}$ scf = 9 Tcf

Frigg : $G_g \sim 7 \cdot 10^{12}$ scf (Tcf ↑ $T = 10^{12}$), $r_{si} = 1$ STB/MMscf } N_g = small, $7 \cdot 10^6$ STB

Troll : ~ 45 Tcf = G (G_g) $r_{si} \sim 1$ STB/MMscf

$N_o \sim 5 \cdot 10^9$ STB =

Qatar + Iran (Khuff)

900 (North Field) + 300 (South Pars) Tcf

1200 G_g r_{si} = 25–50 (35) STB/MMscf

NF

$$N_g = G_g \cdot r_{si}$$

$$= \underset{\text{scf}}{900 \cdot 10^{12}} \cdot 35$$

$$= \underset{\text{MMscf}}{900 \cdot 10^{6}} \cdot 35 \cdot \frac{\text{STB}}{\text{MMscf}}$$

$$= \underline{30 \cdot 10^9 \text{ STB}}$$

Dukhan Field Qatar ~$3 \cdot 10^9$ STB

Ghawar Field (Saudi Arabia) ~ $100 \cdot 10^9$ STB $q_o \sim 5 \cdot 10^6$ STB/D

Volumetric Material Balance :

"Accounting" of STBO scf (HCs) STBW

$$N_R = N - N_p + N_{inj}$$

$$G_R = G - G_p + G_{inj}$$

$$W_R = W - W_p + W_{inj}$$

(N ?, N_p ✓, N_{inj} ✓; G ?, G_p ✓, G_{inj} ✓; W ???, W_p (✓), W_{inj} ✓)

$\underline{V_p} = V_{pHC} + V_{pw}$

?

V_{pi} ??? $\Delta V_p(\bar{p}_R)$? c_f c_p

V_p @ $\bar{p}_R$

$$N_R = (N_o + N_g) - (N_{po} + N_{pg}) + N_{inj}$$

$$G_R = (G_g + G_o) - (G_{pg} + G_{po}) + G_{inj}$$

$$W_R = W - W_p + W_{inj}$$

? (1) Connate (Initial) } water sharing pores w/ HCs

+

?? (2) Aquifer } $S_w = 100\%$ lying below Gas & Oil

+

? (3) Non-Net Pay

Gross Pay — $S_w \sim 100\%$, 60–70%, $\lambda_{HC} \sim 0$

=

Net Pay ($\lambda_{HC} > 0$; $\lambda_w \sim 0$)

Non-Net Pay ($\lambda_{HC} = 0$; λ_w low > 0)

N, G, W uncertain

⇓

Surface Volumes that distribute between 3 reservoir fluid phases g o w

V_{pi} uncertain

e.g. { 6·10⁹ STB, 9 Tscf surface } gas in Ekofisk

{ 'distributed' only into the initial reservoir OIL phase

{ $900 \cdot 10^{12}$ scf STO, $30 \cdot 10^9$ STB condensate } in North Field only distributed into the initial reservoir

GAS phase

V_{pi} contains all N G W @ p_{Ri} $t=0$

V_{pgi} ? V_{poi} ? V_{pwi} ?

N_g N_o (N_w) ~ 0 G_g G_o G_w (>0) W_g (>0) W_w W_o (~ 0)

Initial

V_{pg} V_{po} V_{pw}

$V_p \leq V_{pi}$

N_{Rg} N_{Ro} G_{Rg} G_{Ro} W_{Rw} $t>0$

Initial − Produced + Injected surface volumes

Need Black-Oil PVT Properties: Compositional

Oil Phase: $\checkmark R_{si} = \frac{G_o}{N_o}$ initial solution GOR $(x_{Ri})_{t=0}$

Gas Phase $\checkmark r_{si} = \frac{N_g}{G_g}$ initial solution OGR @ p_{Ri} $(y_{Ri})_{t=0}$

Total Reservoir GOR $= \frac{G}{N}$ $(z_{Ri})_{t=0}$

$t>0$:

Oil Phase $R_s = \frac{G_{Ro}}{N_{Ro}}$ (p_R) solution GOR @ $\bar{p}_R$ $(x_{Ri})_t$

$(K_i)_t @ p_R$

$r_s = \frac{N_{Rg}}{G_{Rg}}$ (p_R) solution OGR @ $\bar{p}_R$ $(y_{Ri})_t$

Total Remaining Reservoir GOR $= \dfrac{G_R}{N_R}$ $\quad (Z_{Ri})_t$

How to fill V_p with $\underbrace{G_R \quad N_R \quad W_R}$

BO PVT $\quad B_o(p_R)$ & $\quad B_{gd}(p_R)$

p_R @ $\underline{B_o}$ $= \dfrac{(V_{po})}{N_{Ro}} = \dfrac{\text{Reservoir Oil Volume}}{\text{STB surface Oil from Res. Oil}}$

p_R @ $\underline{B_{gd}}$ $= \dfrac{(V_{pg})}{G_{Rg}} = \dfrac{\text{reservoir Gas Volume}}{\text{surface scf gas from Res Gas}}$

p_R @ $\underline{B_w}$ $= \dfrac{V_{pw}}{W_{Rw}} = \dfrac{\text{reservoir water volume}}{\text{surface STBW from Res. Wat}}$

$V_{pi} \cong V_p = V_{pg} + V_{po} + V_{pw}$

Standard Solution Method of the Volumetric Mat. Bal.

① Assume $\underline{G}$ $\underline{N}$ $\underline{W}$ @ $t=0$ @ p_{Ri}

② Initial RG and/or RO ?

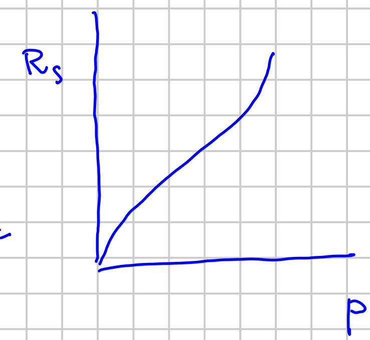
$$\underline{\underline{R_i}} = \frac{G}{N}$$

Initial Reservoir Gas-Oil Ratio $(R_{Ri})_{t=0}$

BOPVT : Solution GOR vs p

$R_s(p)$ — RO

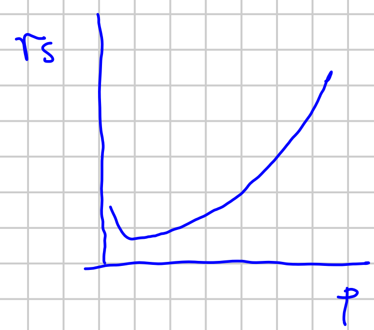
$1/r_s(p)$ — RG

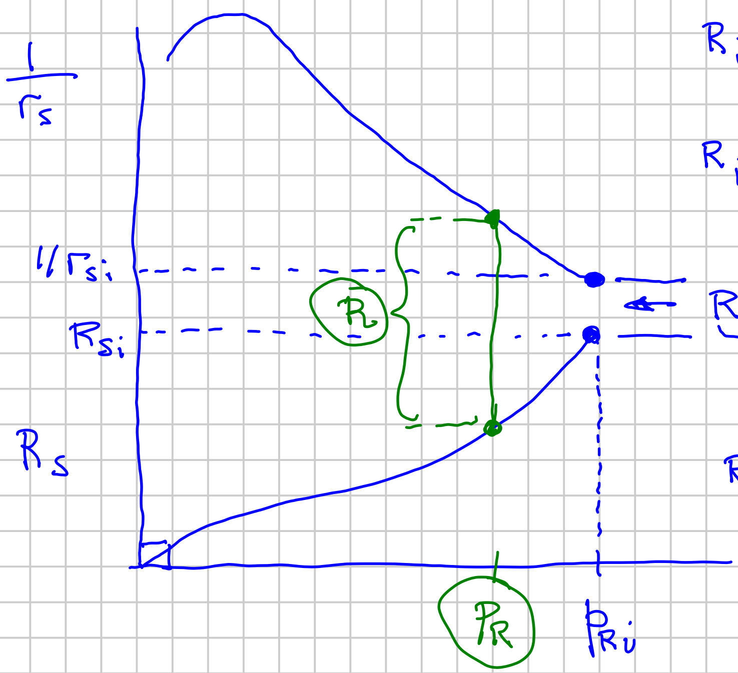


$R_i > \frac{1}{r_{si}}$: Undersat. Gas

$R_i = \frac{1}{r_{si}}$: Sat. Gas

$R_i \geq \frac{1}{r_{si}}$: Gas Phase Only





$R_{si} < R_i < 1/r_{si}$ — Reservoir has two phases RG + RO

$R_i \leq R_{si}$: Oil phase Only

$R_i = R_{si}$: Initial Saturated Oil

$R_i < R_{si}$: Initial Undersaturated Oil

(3a) G only $\Rightarrow B_{gd,i}$ @ P_{Ri} $V_{pgi} = G \cdot B_{gd,i}$

O only B_{oi} @ P_{Ri} $V_{poi} = N \cdot B_{oi}$

(3b) G+O $B_{gd,i}$ & B_{oi} —"—

G < G_g, G_o

N < N_g, N_o

✓ $G = G_g + G_o$

$= G_g + R_{si} N_o$

✓ $N = N_g + N_o$

$G_g r_{si} + N_o$

✓ $R_{si} = \frac{G_o}{N_o}$ ✓ $r_{si} = \frac{N_g}{G_g}$

$\Rightarrow G_g \quad G_o \quad N_g \quad N_o$

$V_{pgi} = G_g \cdot B_{gd,i}$

$V_{poi} = N_o \cdot B_{oi}$

(4) $V_{pw} = W \cdot B_{wi}$

(5) $\boxed{V_{pi}} = V_{pgi} + V_{poi} + V_{pwi}$

(1) → (5) or (5) → (1)

Start Depletion:

(A) Actual Production, Injection data and measured p_R vs time

G_p N_p W_p G_{inj} W_{inj} p_R

(B) Forecasting with no history

(A) $G_R = G - G_p + G_{inj}$

$N_R = N - N_p$

$W_R = W - W_p + W_{inj}$

① G_R N_R W_R @ p_R

② $R = \frac{G_R}{N_R}$ exact same as ② initially

but R instead R_i

p_R — " — p_{Ri}

⇒ RG only

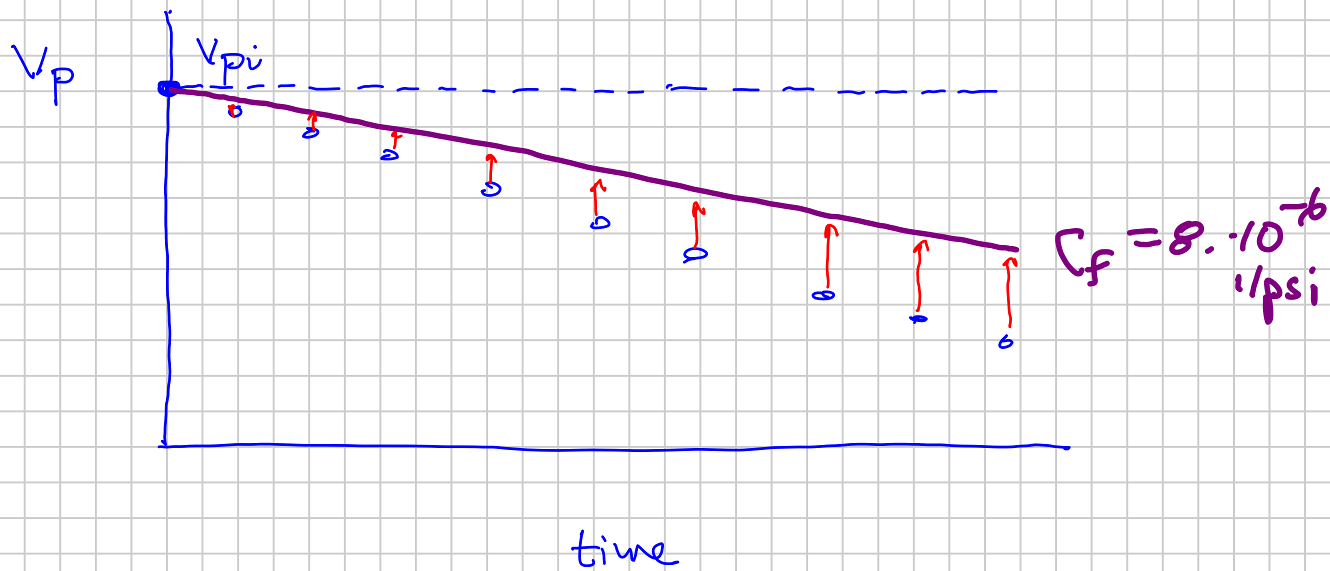
RG + RO

RO only

③ same V_{pg} V_{po}

4. same V_{pw}

5. V_p @ p_R



$V_p(p_R)$: $c_f(p)$ rock, formation

$c_f \sim$ const pore compressibility

Video on YouTube