Curtis Hays Whitson

RESERVOIR & PRODUCTION ENGINEERS

- Mechanisms of Recovery (Depletion | EOR)
  - EOR: Water | Gas | Other Injecting
- Rate of Recovery:
  - Reservoir: Darcy+
  - Near-Well: Darcy++
  - Wells & Equipment: Pipe

Require Quantitative Description of

Phase & Volumetric Properties of Fluids Flowing

- HC's: Gas, Oil
- Water

"PVT"

Pressure-Volume-Temperature

PVT Properties:

① μ ρ $c = \frac{1}{\rho}\left(\frac{d\rho}{dp}\right)_T$ | z_i (molar composition), y_i (gas), x_i (oil), f_g | σ_{go}, σ_{wo} (Surface Tension, IFT) | D_{ig}, D_{io}

$f(p, T;\ z_i | y_i | x_i)$

- μ, ρ, c: Phase Properties (for a given composition)
- z_i, y_i, x_i, f_g, σ_{go}, σ_{wo}: Two-phase (g+o) Phase Properties
- D_{ig}, D_{io}: Component-in-a Phase Property

② B (b) R_s r_s (R_v)

Volume Factor

Gas-Oil Ratio (R_s)

Oil-Gas Ratio (r_s, R_v)

Products

Surface

Surface Gas   SG $V_{\bar{g}}$

@ $T_{sc} \sim 60°F$ (15.56°C)

$p_{sc} \sim 1$ atm

Surface Oil

SO $V_{\bar{o}}$

STO

(a) V_g [bbl] single Phase

(b) V_o (p, T)

$1.05 < B_{oi} < 3.5$

$$B_o \equiv \frac{V_o(p,T)}{V_{\bar{o}}} \quad \text{(Oil Phase @ (p,T))}$$

$\frac{bbl}{bbl @ ST} = \frac{bbl}{STB}$ e.g. $B_{oi} \simeq 2$

$$b_o \equiv \frac{1}{B_o} = \frac{V_{\bar{o}}}{V_o(p,T)}$$

Shrinkage Factor

$SF_i = b_{oi} = \frac{1}{2}$

Solution GOR

$$R_s \equiv \frac{V_{\bar{g}}}{V_{\bar{o}}}$$

e.g. $1500 \frac{scf}{STB} \sim 300 \frac{Sm^3}{Sm^3}$ Ekofisk

---

Gas Phase @ (p,T)

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

$0.02 > B_{gi} > 0.003$

$$b_g = \frac{1}{B_g} = \frac{V_{\bar{g}}}{V_g(p,T)}$$

Expansion $50 < b_g < 350$

B_g m^3/Sm^3

ft^3/scf

$bbl/Mscf$

R_v $r_s \equiv \frac{V_{\bar{o}}}{V_{\bar{g}}}$ ← Condensed Out @ Surface

Solution Oil-Gas Ratio

OGR

Sm^3/Sm^3 $Sm^3/10^6 Sm^3$ $\frac{STB}{10^6 scf}$ $\frac{STB}{MMscf}$

Gas Reservoir | Oil Reservoir | Gas+Oil Reservoir

- What's the difference between Gas & Oil Reservoir

- Is the difference important?
- What is RF
- What is Gas?

  What is oil?

  What is a Reservoir? Rock w/ pores

GAS | OIL

$0.02 < \mu_g < 0.1\ cp$ $\quad 0.1\ cp < \mu_o < 10^6\ cp$

$cp = mPa \cdot s$

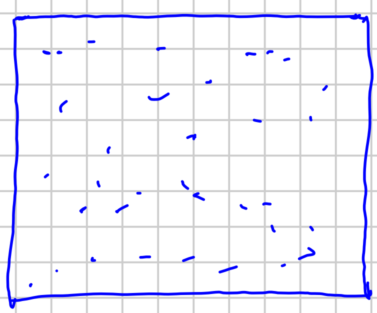
filling pores @ 100 bar

filling pores @ 1 atm

$RF = \frac{n_i - n_f}{n_i}$

$P_{R_i} = 100$ bar

$P_{final} = 1$ bar



$pV \cong nRT$

Gas

① Pure CO_2 $\quad RF \sim 99\%$ (Ideal Gas Law)

② Pure H_2O $\quad RF$ very low
Liquid

0.5 %

$c_w = \frac{1}{V}\frac{\Delta V}{\Delta p} \sim 3 \cdot 10^{-6}\ psi^{-1}$

$\times 14.5 \frac{psi}{bar}$

$\sim 50 \cdot 10^{-6}\ bar^{-1}$

$RF \simeq \frac{\Delta V}{V} = 50 \cdot 10^{-6}(100)$

$= 50 \cdot 10^{-4}$

$= 0.005$

$\sim 0.5\%$

③ Carbonated Water

RF 0-100%

Liquid

H_2O saturated with CO_2 @ 100 bar

$$R_s = \frac{V_{\bar{g}}}{V_{\bar{o}}} = \frac{V_{\overline{CO_2}}}{V_{\bar{w}}} = 1 \ Sm^3/Sm^3$$

RF ~ 0-100%

④ Water-Saturated CO_2

RF ~ 99% +

Gas

CO_2 saturated with H_2O @ 100 bar

r_{s_i} 100 bar, T_i $\quad$ r_{s_f} 1 bar, T_f

5 $\quad$ 1

5-1 => condensed water in the pores

4 cc @ 1 bar