RESERVOIR RECOVERY METHODS

Note Title 9/3/2018

(A) DEVELOPMENT METHODS

① Smaller and often Onshore Projects

(G&G) Drill – Discover (HCs) – Produce – Monitor – Modeling (HM) ⇒ Forecasting (& Today's optimization) q's p's

Theory
Eqs.
Num. methods
Data
Tune
History Matching

② Larger and Usually offshore Projects

G-G – Drill – Discover (HCs) – (Might Start Production Test) – Drill & Delinication –

(a) Modeling (???) – Design – PDO
Planned Development Operation

Sensitivity Analysis
Statistics
Monte Carlo

– Development – Produce – Monitor – (b) Modeling (HM) ⇒

Forecasting (& Today's optimization)

(B) Modeling Methods $p_R(Q_p)$ N_p N

① (Volumetric) Material Balance : $p_R = f(p_{R_i}, Q_p, Q_i ; Q_{inj})$

Product Volumes

$\boxed{k \gtrsim 0.01 - 0.1}$

G_p IGIP G

[OIP IGIP WIP]$^{\text{INITIAL}}$ = Produced − Injected + Remaining

Sm^3 STB Mscf

(a)

e.g. Gas M.B. "Pot Aquifer"

$$\frac{p_R}{Z_{gR}}\left[1 - c_e\left(p_{R_i} - p_R\right)\right] = \left(\frac{p_{R_i}}{Z_{gi}}\right)\left(1 - \frac{G_p}{G}\right)$$

G_p = Cum. Gas (Surface Gas Product) Produced

G = IGIP (— " —)

$p_R(Q_p)$

(b) Each and All RFUs

Aside : Reservoir Simulation of Depletion

$N_{cells} \simeq N_{RFU}$

if ands and buts (k sufficiently high)

$p_R \sim p(X, Y, Z)$

during $\Delta t = 1\text{–}6$ mo.

② Approximate Flow Equations

- Mainly Darcy (In reservoir w/ reservoir rates / surface product rates)
- Depletion
  - Surface Rate Eq.

$$q_g = \frac{kh\,(p_{pR} - p_{pwf})}{T_R \cdot \Big[\underbrace{\ln\frac{r_e}{r_w}}_{7-10} + s + Dq\Big]} = \underbrace{\frac{dG_p}{dt}}$$

$$p_p \equiv 2\int_{p_{ref}}^{p} \frac{p'}{\mu Z}\,dp'$$

Single Phase Oil

M.B.

$$\frac{dQ_o}{dt} = q_o = \frac{kh\,(p_R - p_{wf})}{\mu_o B_o\left[\ln\frac{r_e}{r_w} + s\right]} = \frac{dN_p}{dt}$$

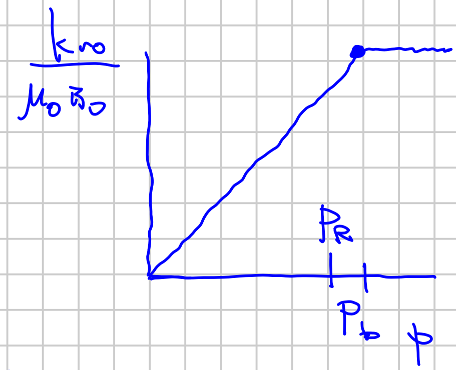
STB/D

Sm³/D

$$-6 < s < +100$$

S&D $\quad p_R < p_b$

$$q_o = \frac{k_{ro}\,kh\,(p_R^2 - p_{wf}^2)}{\mu_{ob}B_{ob}(2p_b)\left[\ln\frac{r_e}{r_w} + s\right]}$$

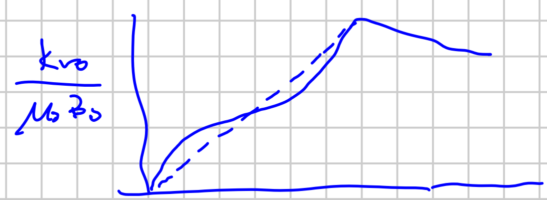


Fetkovich

Alt. ⇒ Vogel (100s of Simulations)

Muskat (1930s-40s)

Meyers



$$\left\{\begin{array}{ll} \text{MB}: & p_R(Q_p) \\ \text{Rate}: & q = \dfrac{dQ_p}{dt} = \text{constant} = PI\,(p_R - p_{wf}) \end{array}\right.$$

$$\boxed{\begin{array}{l} q(t) \Rightarrow \text{Forecast} \\ \qquad (\text{Today's Optimization}) \end{array}}$$

Arp's Decline Curve Eq. : $\underbrace{MB} + \underbrace{\text{"IPR"}} \Rightarrow q(t)$

$$q = \frac{q_i}{\left[1 + bDt\right]^{1/b}}$$

$$q_i = PI\,(p_R - p_{wf}) = \text{constant}$$

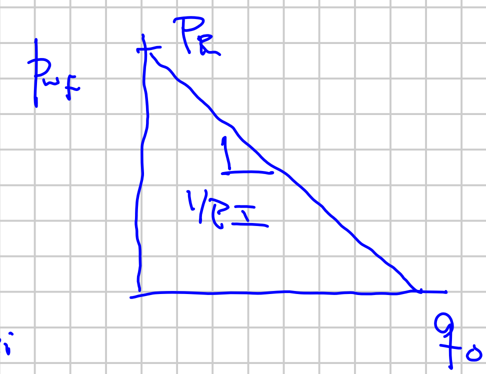
$0 < b < 0.5$ <
- Single phase, low c oil
- Low Pressure Gas
- SGD

Decline Constant

$$D \equiv \underbrace{\frac{q_i}{\underbrace{(Q_i \cdot RF_{ult})}_{\text{"EUR"}}}}_{\text{"Rate of Depletion"}} \cdot \frac{1}{1-b}$$

Contrast $\Rightarrow$ "Differential Depletion"

RFU_1 vs RFU_2

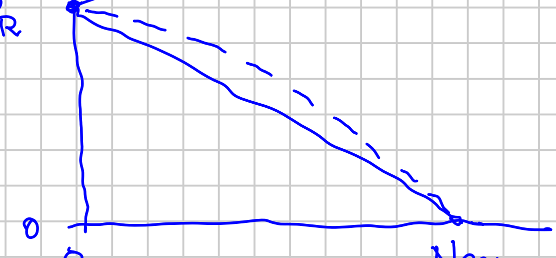


Homework Fun:

$$q_o = PI\,(\underbrace{p_R - p_{wf}}_{\text{const}})$$

$p_R(t)$

$$p_R = p_{Ri}\left(1 - \frac{N_p}{N_{pult}}\right)$$



"EUR" = N_{pult} / N

$\Rightarrow$ Arp's Decline Eq.?

EOR : Displacent of Insitu Fluid by Injected Fluid

- Two or more wells ($I \rightarrow Ps$)
- $v_D = \frac{k}{\mu} \cdot \frac{dp}{dx}$ Darcy Velocity

  - Injected (w)
  - Produced (o)

$$v_{wD} = \overbrace{\left(\frac{k_w}{\mu_w}\right)}^{\lambda_w} \frac{dp_w}{dx} = k\left(\frac{k_{rw}}{\mu_w}\right)\frac{dp_w}{dx}$$

$$v_{oD} = \underbrace{\left(\frac{k_o}{\mu_o}\right)}_{\lambda_o} \frac{dp_o}{dx} = k\left(\frac{k_{ro}}{\mu_o}\right)\frac{dp_o}{dx}$$

@ Reservoir Conditions

$p_w \simeq p_o$

Mobility $\lambda \equiv \frac{k}{\mu}$ md/cp

Behind Front

$$M \equiv \frac{(k_{rw}/\mu_w)}{(k_{ro}/\mu_o)} = \underbrace{\left(\frac{k_{rw}}{k_{ro}}\right)}_{\text{Rock}} \underbrace{\left(\frac{\mu_o}{\mu_w}\right)}_{\text{Fluid}}$$

Mobility Ratio

Ahead of Front

Rel. Perm. Ratio   Viscosity Ratio

Fractional Flow (Ratio) $f_w(S_w) \equiv \frac{v_{wD}}{v_{wD} + v_{oD}}$

$$= \frac{1}{1 + \frac{k_{ro}}{k_{rw}}(S_w)\,\frac{\mu_w}{\mu_o}}$$

$k = 200$ md

$k = 100$ md

$h_1 = h_2$

Breakthrough occurs at the Same Time in both layers. $\phi_{L1} = 0.2$ $\phi_{L2} = 0.10$

Transport $v \neq v_D$

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