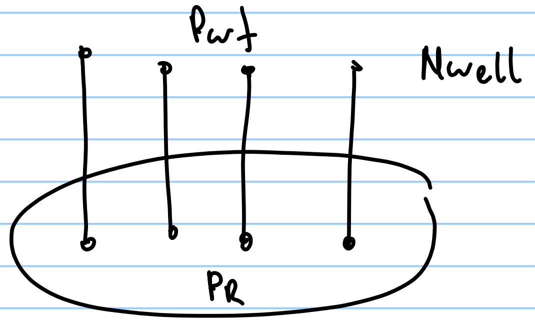


$$q_g = C\left(P_R^2 - P_{wf}^2\right)^n$$

$$q_f = N_{wells}\, C\left(P_R^2 - P_{wf}^2\right)^n$$

$$q_{f\_potential} = q_f\left(P_{wf} = P_{wf\,min}\right) = N_{wells}\, C\left(P_R^2 - P_{wf\,min}^2\right)^n$$

if $q_{f\_target\,rate} < q_{f\_potential}$ then

$$q_f = q_{f\_target\_rate}$$

?

$$q_{f\_target\,rate} = N_{well}\, C\left(P_R^2 - P_{wf}^{*2}\right)^n$$

else $q_{f\_target\,rate} \geq q_{f\_potential}$ then

$$q_f = q_{f\_potential}$$

$$P_{wf} = P_{wf\,min}$$

to improve calculations:

$$z \qquad P\,\underset{1/\rho}{V} = zRT$$

$$z = f\left(P_r, T_r\right) \qquad P_r = \frac{P}{P_c} \qquad T_r = \frac{T}{T_c}$$

$$\gamma_g = \frac{MW_g}{MW_{air}} = \frac{MW_g}{28.97}$$

$$MW_g = \sum_{i=1}^{N_{comp}} z_i\, MW_i$$

Sutton[1] suggests the following correlations for hydrocarbon gas mixtures.

$$T_{pcHC} = 169.2 + 349.5\gamma_{gHC} - 74.0\gamma_{gHC}^2 \quad (3.47a)$$

and $p_{pcHC} = 756.8 - 131\gamma_{gHC} - 3.6\gamma_{gHC}^2$. (3.47b)

accurate representation of the Standing-Katz chart using a Carnahan-Starling hard-sphere EOS,

$$Z = \alpha p_{pr}/y, \quad (3.42)$$

where $\alpha = 0.06125t \exp[-1.2(1-t)^2]$, where $t = 1/T_{pr}$.

The reduced-density parameter, y (the product of a van der Waals covolume and density), is obtained by solving

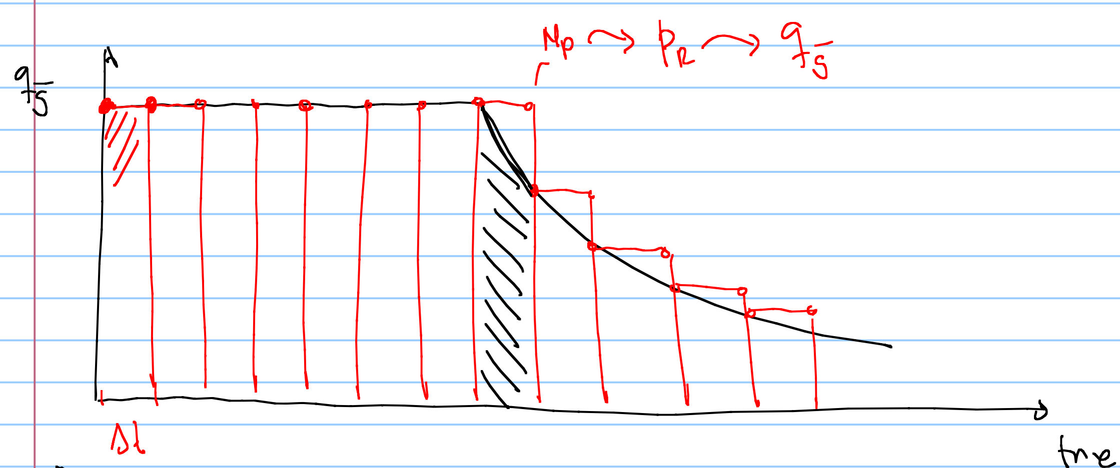
$$\begin{aligned} f(y) = 0 = &-\alpha p_{pr} + \frac{y + y^2 + y^3 - y^4}{(1-y)^3} \\ &- (14.76t - 9.76t^2 + 4.58t^3)y^2 \\ &+ (90.7t - 242.2t^2 + 42.4t^3)y^{2.18+2.82t}, \end{aligned} \quad (3.43)$$

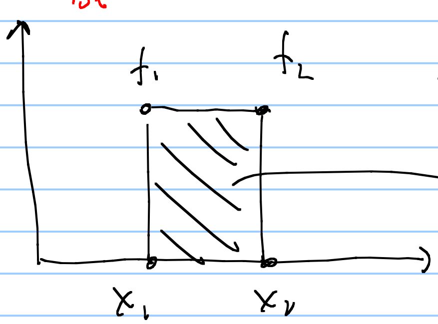
with

$$\begin{aligned} \frac{df(y)}{dy} = &\frac{1 + 4y + 4y^2 - 4y^3 + y^4}{(1-y)^4} \\ &- (29.52t - 19.52t^2 + 9.16t^3)y \\ &+ (2.18 + 2.82t)(90.7t - 242.2t^2 + 42.4t^3) \\ &\times y^{1.18+2.82t}. \end{aligned} \quad (3.44)$$

The derivative $\partial Z/\partial p$ used in the definition of c_g is given by

$$\left(\frac{\partial Z}{\partial p}\right)_T = \frac{\alpha}{p_{pc}}\left[\frac{1}{y} - \frac{\alpha p_{pr}/y^2}{df(y)/dy}\right]. \quad (3.45)$$





trapezoidal rule

$$\text{Area} = (f_1 + f_2)\frac{(x_2 - x_1)}{2}$$

at time "i" t_i , q_i ΔG_{i+1}

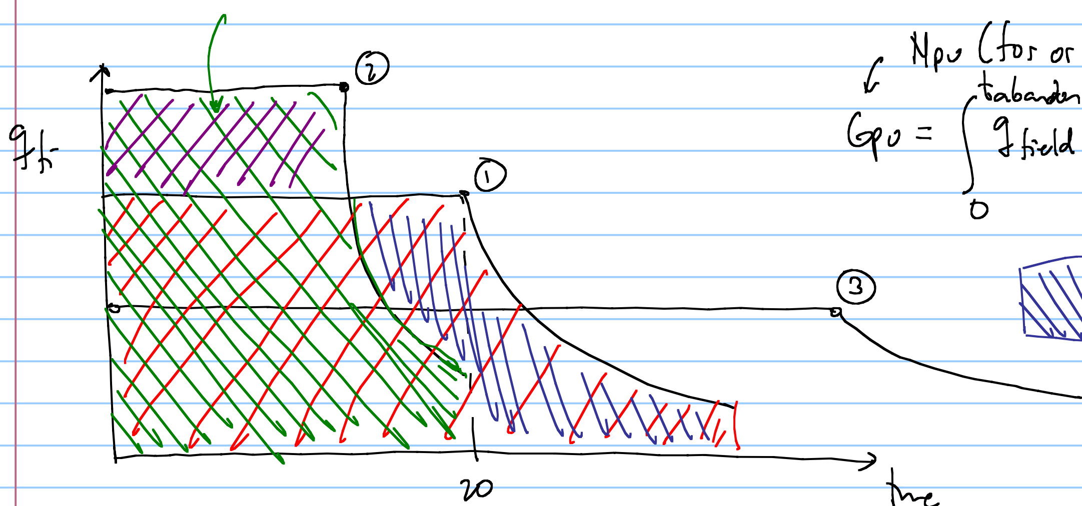
time	q	Gp	ΔGp	P_R
⋮				
t_i	q_i	Gp_i		
t_{i+1}	q_{i+1}?	Gp_{i+1}	ΔGp_i	

$$Gp_{i+1} = Gp_i + \Delta Gp_i$$

rectangular approximation $\Delta Gp_i = q_i (t_{i+1} - t_i) \cdot Ndays/year$

$$\Delta Gp_i = \frac{(q_i + q_{i+1})(t_{i+1} - t_i)}{2}$$

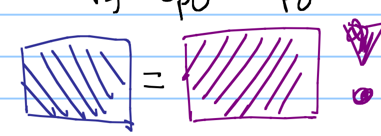
(implicit integration method that requires iterative solving !)



Np_u (for oil)

$$Gp_u = \int_0^{t_{abandonment}} q_{field}\, dt$$

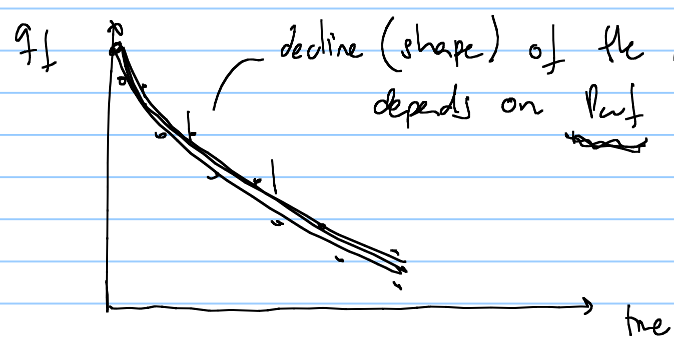
if $Gp_u^{①} = Gp_u^{②}$



$$\underbrace{Gp_u^{①} \approx Gp_u^{②} \approx Gp_u^{③}}$$

the higher plateau ⇝ the shorter the plateau

• if operating in constant pressure mode



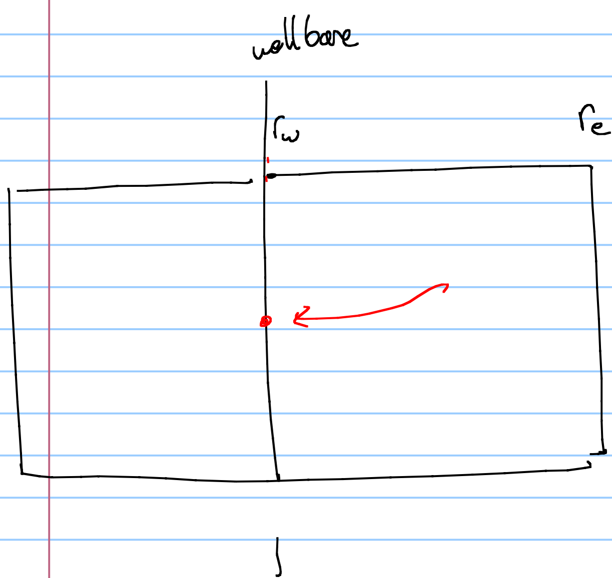
decline (shape) of the slope depends on P_{wf}

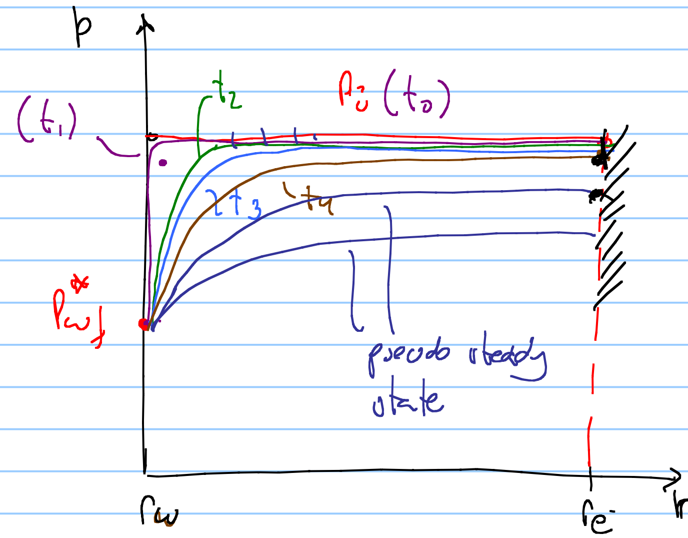
Short comment on IPR equation used:

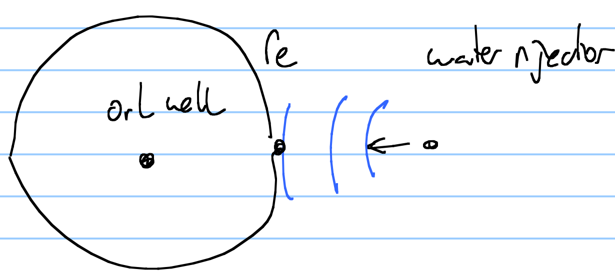
Backpressure gas equation $q_g = C(P_R^2 - P_{wf}^2)^n$

→ • steady state or pseudo steady state regime
SS PSS

• low pressure (~100 bara)







time from $t_0 - t_4$ (when rate changes reach boundary)
↳ transient regime

t_{ss} t_{pss}
↓ time to steady state
→ time to pseudo steady state

t_{ss} is $f(k)$
↳ permeability

• if t_{ss}, t_{pss} is long (months, years)
shale gas, shale oil, tight oil, tight oil

• after transient if $P(r_e)$ = constant
then steady state

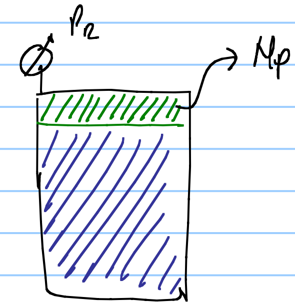
in SS, PSS $q_{well} = f(P_R, P_{wf})$

in transient $q_{well} = f(P_i, P_{wf}, t)$

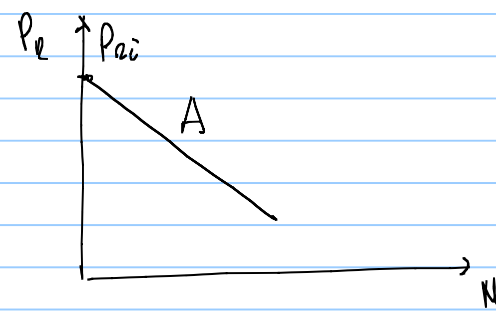
- Undersaturated oil reservoir with underlying large aquifer

  $P_R > P_b$ for whole production time (no gas in formation)

  $P_{wf} > P_b$ — bubble point pressure



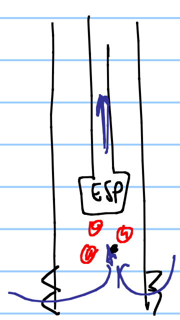
$$P_R = P_{Ri} - A \cdot N_p$$



$$A = \frac{B_o(p)}{\underbrace{N}_{\text{initial oil in place}} B_{oi} C_o + N B_{oi} \overbrace{\frac{C_w \cdot S_w + C_f}{S_o}}^{\text{compressibility}} + \underbrace{V_a}_{\text{aquifer volume}} \phi_a (C_w + C_f) B_w}$$

$$R_f = \frac{N_{po}}{N}$$

- wells are operated with ESP electric submersible pumps



there is a $P_{wf\,min}$

$$P_{wf\,min} = P_b\,(T_R)$$

$$q_{well} = J\,(P_R - P_{wf})$$

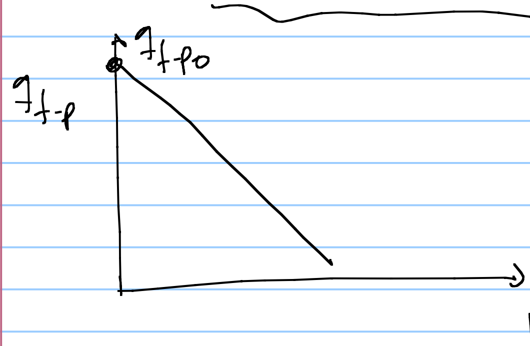
· flow of liquid only

$$q_{field} = N_{wells} \cdot J \left(P_R - P_{wf}\right)$$

$$q_{field\_potential} = N_{wells} \cdot J \left(P_{Ri} - A\, \underline{N_p} - P_{wf\,min}\right)$$

$$q_{field\_potential} = \underbrace{-N_{well} \cdot J \cdot A}_{m}\, N_p + \underbrace{N_{well} \cdot J \left(P_{Ri} - P_{wf\,min}\right)}_{q_{f\text{-}po}}$$

$$\underline{q_{f\text{-}p} = -m\, N_p + q_{f\text{-}po}}$$



$$q_{plateau} = q_{f\text{-}p} = -m\, N_p^{*} + q_{f\text{-}po}$$

if

$N_p = 0 \longrightarrow N_p^{*}$

$q_{field} = q_{plateau}$

$N_p^{*} = q_{plateau} \cdot t_p \cdot \frac{N_{day}}{year}$

plateau duration

$$q_{plateau} = -m\, q_{plateau} \cdot t_p \cdot N_{days/year} + q_{f\text{-}po}$$

$$t_p = \frac{q_{f\text{-}po} - q_{plateau}}{m\, q_{plateau} \cdot N_{day/year}}$$

$$t_p = \frac{1}{N_{day}} \frac{1}{m} \left(\frac{q_{fpo}}{q_{plateau}} - 1\right)$$

$$t_p = \frac{1}{N_{dy}} \frac{1}{N_w \cdot A \cdot J} \left(\frac{\left(P_i - P_{wf\,min}\right) J \cdot N_{wells}}{q_{plateau}} - 1\right)$$

$$t_p = \frac{1}{N_{days}} \, \frac{1}{\underline{A}} \left(\frac{p_i - \overline{p_{wf\,min}}}{q_{plateau}} - \frac{1}{N_w \cdot J} \right)$$

Bigger reservoir ($\uparrow N$) $\rightarrow$ $\downarrow A$ $\rightarrow$ $\uparrow t_p$

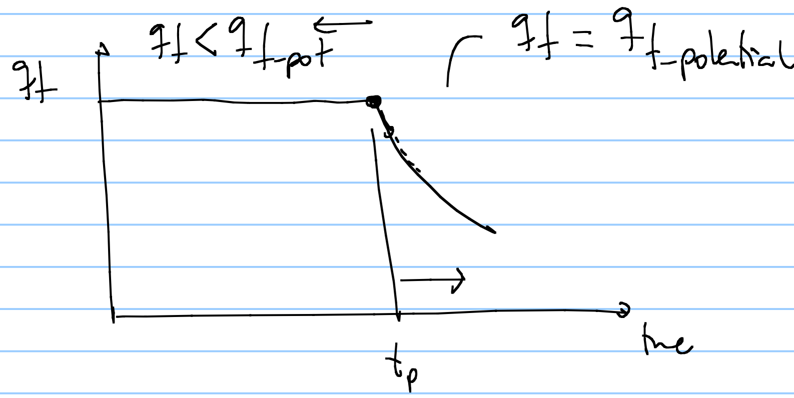
more wells ($\uparrow N_w$) $\rightarrow$ $\uparrow t_p$

more productive wells ($\uparrow J$) $\rightarrow$ $\uparrow t_p$

lower p_{wf_min} $\rightarrow$ $\uparrow t_p$

higher plateau $\uparrow q_{plateau}$ $\rightarrow$ $\downarrow t_p$

post plateau rate?



$$q_{f-p} = -m \, \underset{\sim}{N_p} + q_{f-po}$$

$$N_p = \int_0^t q_f \, dt = \underbrace{\int_0^{t_p} q_{pla} \cdot dt}_{\text{plateau}} + \underbrace{\int_{t_p}^{t} q_{f-p} \, dt}_{\text{decline}}$$

$$q_{f-p} = -m \, q_p \cdot t_p - m \cdot \int_{t_p}^{t} q_{f-p} \, dt + q_{f-po}$$

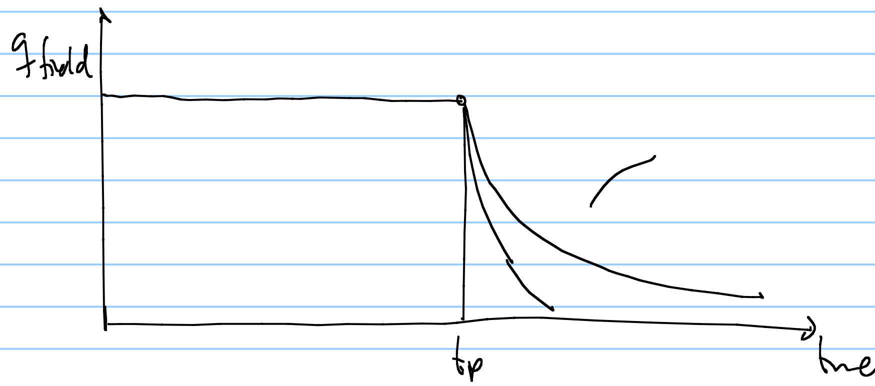
$$t_p = \frac{1}{m} \left(\frac{q_{f-po}}{q_{plateau}} - 1 \right)$$

$$q_{f-p} = q_{plateau} - m \int_{t_p}^{t} q_{f-p} \, dt$$

a solution of this equation is

$$q_{f-p} = q_{plateau} \cdot e^{-m(t-t_p)}$$

A , Nwells , J



if N^{OOIP} ↑ A ↓ longer decline

if Nwells ↑ m ↑ sharper decline

if J ↑ m ↑ sharper decline