Single-Phase Liquid (Oil) Reservoir Rate Eq.

Steady State:

$$\Omega = \frac{1}{141.2\, \mu_o B_o \cdot \ln r_e/r_w}$$

$$q_o = \frac{kh\,(p_e - p_{wf})}{141.2\, \mu_o B_o \cdot \ln r_e/r_w} = \Omega\, kh\,(p_e - p_{wf})$$

$$= J_o\,(p_e - p_{wf})$$

$\uparrow$

Productivity Index

q_o [STB/D]

k [md] h [ft]

p [psi]

μ_o [cp] B_o [-]

r_e, r_w [ft]

$$J_o = \frac{kh}{141.2\, \mu_o B_o \ln r_e/r_w}$$

STB/D/psi

Quantity	Unit	Range	O.O.M.
k	md	$\overset{10^{-5}}{\underbrace{10\cdot 10^{-6}}_{10\text{ nd}}} \cdot 0.001 - \overset{10^{4}}{10{,}000}$	$\boxed{7-9}$

$1 \text{ md} = 10^{-3} \text{ D}$

$1 \text{ nd} = 10^{-9} \text{ D} = 10^{-6} \text{ md}$

(net) h	ft	$10 - \underset{\times 000}{1000}$ ft	$\boxed{2}$
p_e (p_{Ri})	psi	100 - 15,000	$\boxed{2}$
μ_o	cp	0.1 - 10,000 cp	$\boxed{5}$
μ_g	cp	0.01 - 0.1	$\boxed{1}$

B_o	vol/vol	1.05 – 3(4)	<1
$\ln r_e/r_w$	–	5 – 10	<1
J_o	STB/D/psi	0.01 — 1 → 100	$\boxed{4}$

① * p_e is not ever available $\boxed{\bar{p}_R}$ = volumetric average pressure with $r_w \rightarrow r_e$

* SS is very seldom reality

PSS a series of SS conditions where $p_e(t)$

Depletion

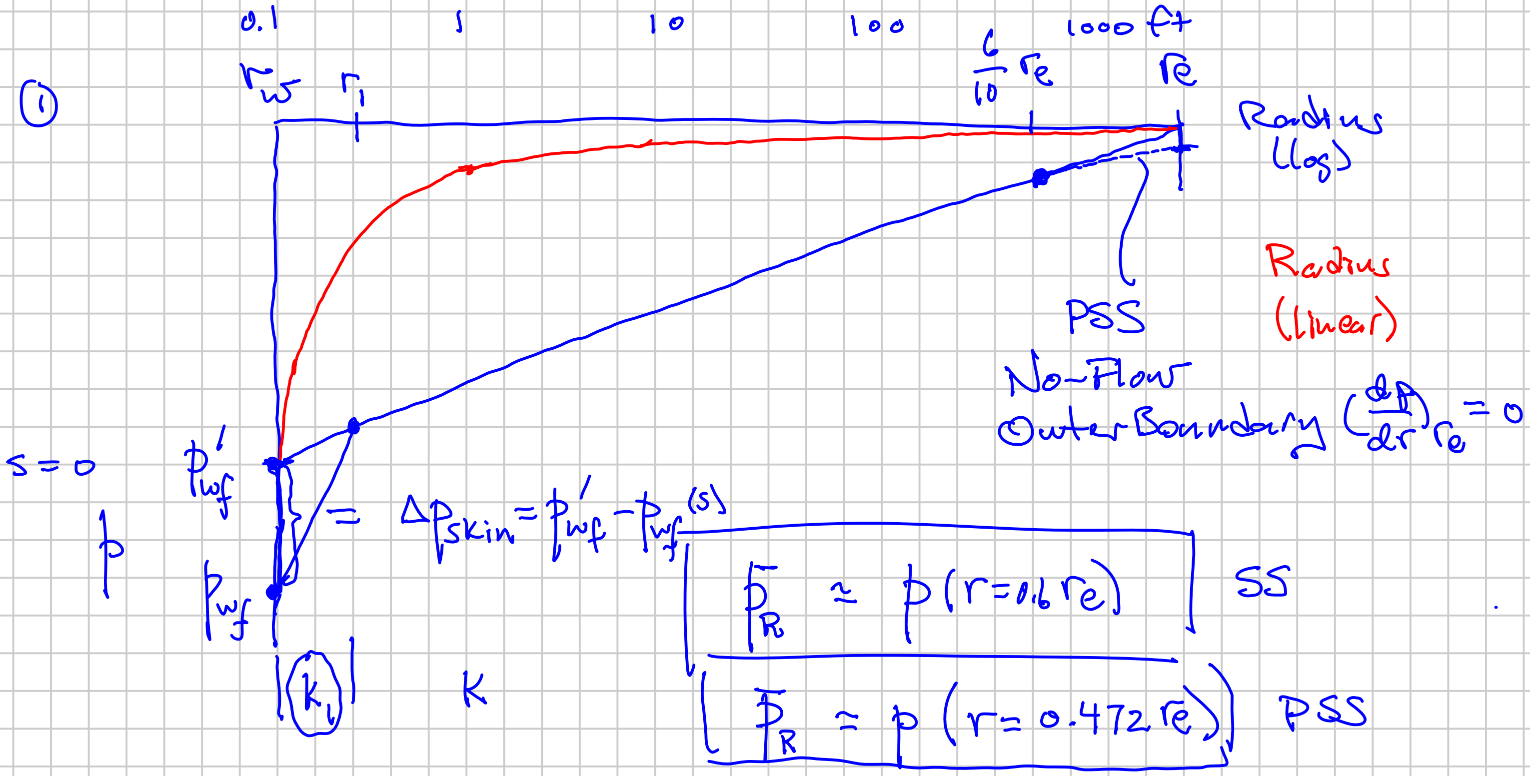
* Sometimes you get a lower perm (damage) very near the wellbore $r_w \rightarrow r_w^+$ (inches → ft)

⇒ "Skin" add pressure drop @ r_w

"s" > 0 extra pressure drop $k_d < k$

s < 0 less — " — $k_s > k$

①



$\} = \Delta p_{skin} = p'_{wf} - p_{wf}(s)$

$\bar{p}_R \simeq p(r = 0.6\, r_e)$ SS

$\bar{p}_R \simeq p(r = 0.472\, r_e)$ PSS

SS: $$q_o = \frac{kh(\bar{p}_R - p_{wf})}{141.2\mu_o B_o\left[\ln\frac{0.6 r_e}{r_w}\right]} = \frac{kh(\bar{p}_R - p_{wf})}{141.2\mu_o B_o\left[\ln\frac{r_e}{r_w} - \frac{1}{2}\right]}$$

PSS: $$q_o = \frac{kh(\bar{p}_R - p_{wf})}{141.2\mu_o B_o\left[\ln\frac{0.47 r_e}{r_w}\right]}$$

PSS: $$\boxed{q_o = \frac{kh(\bar{p}_R - p_{wf})}{141.2\mu_o B_o\left[\ln\frac{r_e}{r_w} - \frac{3}{4}\right]}}$$

Final: PSS Oil Rate Eq.

$$\boxed{q_o = \frac{kh(\bar{p}_R - p_{wf})}{141.2\mu_o B_o\left[\underbrace{\ln\frac{r_e}{r_w} - \frac{3}{4}}_{8} + s\right]}}$$

Δp_{skin} @ r_w

$p'_{wf}(s=0) - p_{wf}(s)$

Dimensionless Skin: Pressure Drop

$0 \rightarrow 100^+$ $s > 0$ Damage

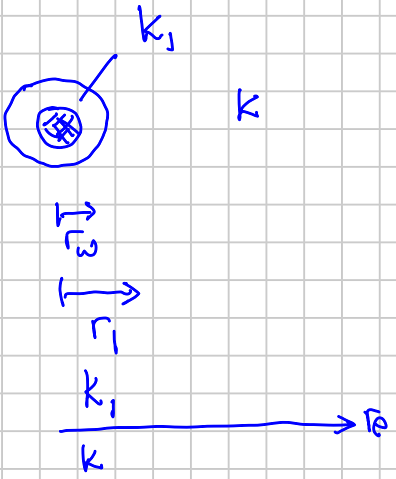
$s \sim -3$ to -5 $s < 0$ Stimulation

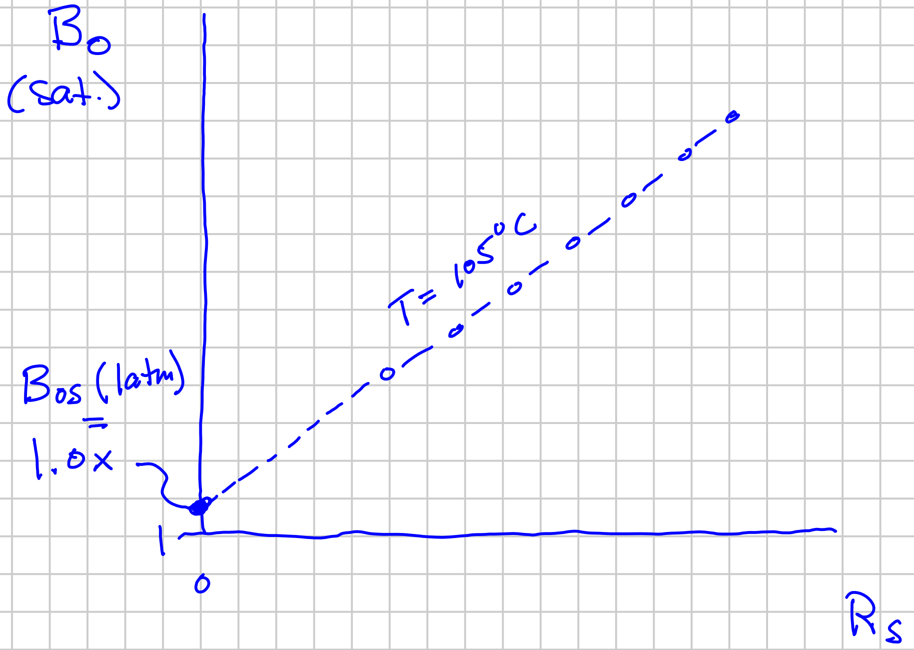
$|s| < \ln\frac{r_e}{r_w} - \frac{3}{4}$

Original Skin (Hawkins)

$$s = \left(\frac{k}{k_1} - 1\right)\ln\frac{r_1}{r_w}$$

Limit $k_1 \rightarrow \infty$ $s = -\ln\frac{r_1}{r_w}$





$$B_o = \frac{V_o(\overset{\checkmark}{T},\ \overset{\downarrow}{p_b} @ \overset{\downarrow}{R_s})}{V_{\bar{o}o}(p_{sc}, T_{sc})}$$

155 °C

$> 1 \Rightarrow$ Shrinkage

① R_s loss

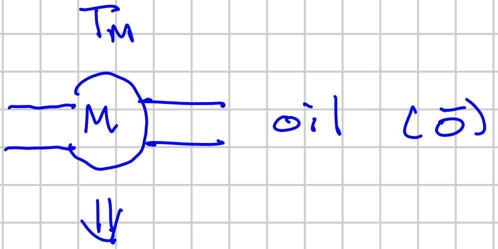
② T to 155°C

1.0x

1.01 − 1.1x

→ T↑

API ↑



⇓

$V_{oM}(T_M) \Rightarrow V_{\bar{o}}(T_{sc} = 60°F) \times \$40.00/STB$

Example: $q_{\bar{o}} = 100$ STB/D (s=0 successful cleanup)

$\Delta p = p_R - p_{wf} = 100$ psi $\qquad \ln\frac{r_e}{r_w} - \frac{3}{4} = 8$

Before Cleanup $s = +8$; $\ln\frac{r_e}{r_w} - \frac{3}{4} = 8$

$$q_o = \frac{kh \quad \Delta p}{141.2\,\mu_o B_o\left[\ln\frac{r_e}{r_w} - \frac{3}{4} + s\right]}$$

Before $\underset{\text{STB/D}}{100} = \frac{kh}{141.2\,\mu_o B_o} \cdot \frac{\Delta p}{(8+8)} \Rightarrow \Delta p = 200$

After $100 = \frac{kh}{141.2 \mu_o B_o} \cdot \frac{100}{8}$ $\Delta p = 100$

STB/D

$$\Delta p_{skin} = s \cdot \frac{q_o \mu_o B_o \, 141.2}{kh}$$

$\underbrace{\Delta p_{skin}}$ during a shut-in $(q_o = 0)$ $= 0$