جامعة الملك سعود
King Saud University

كلية الهندسة
جامعة الملك سعود
King Saud University
College Of Engineering

Well Stimulation and Sand Production Management (PGE 489)

Skin Effect and Formation Damage

By
Dr. Mohammed A. Khamis

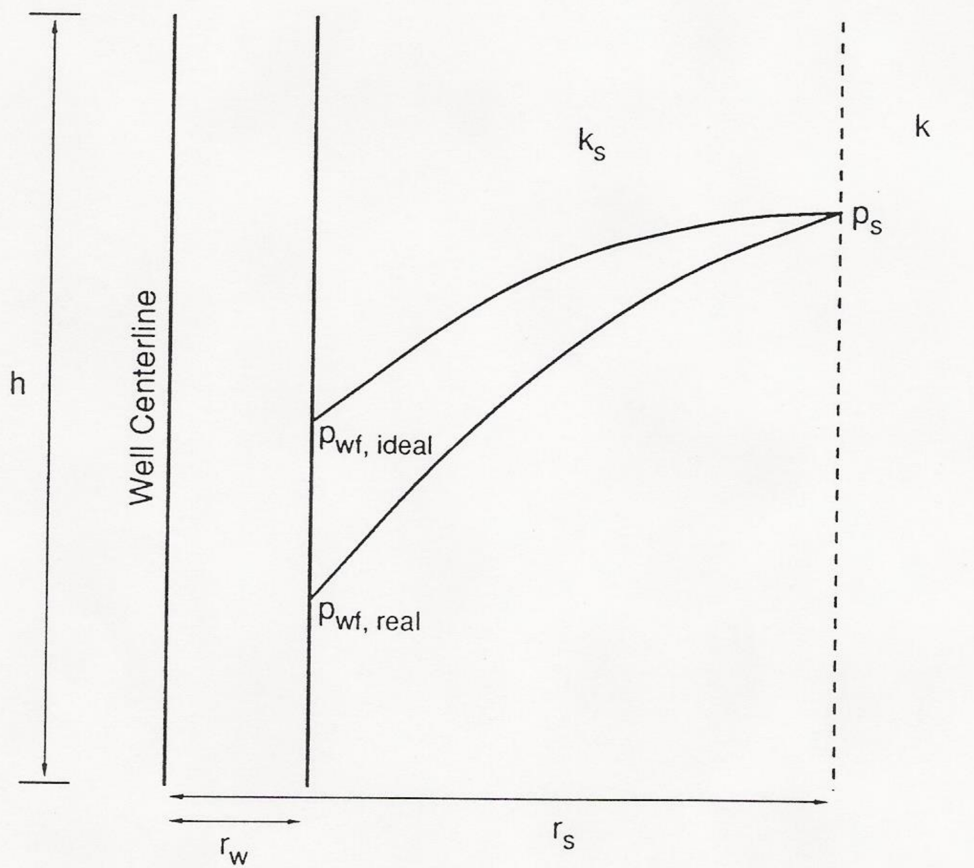
02-02-2016

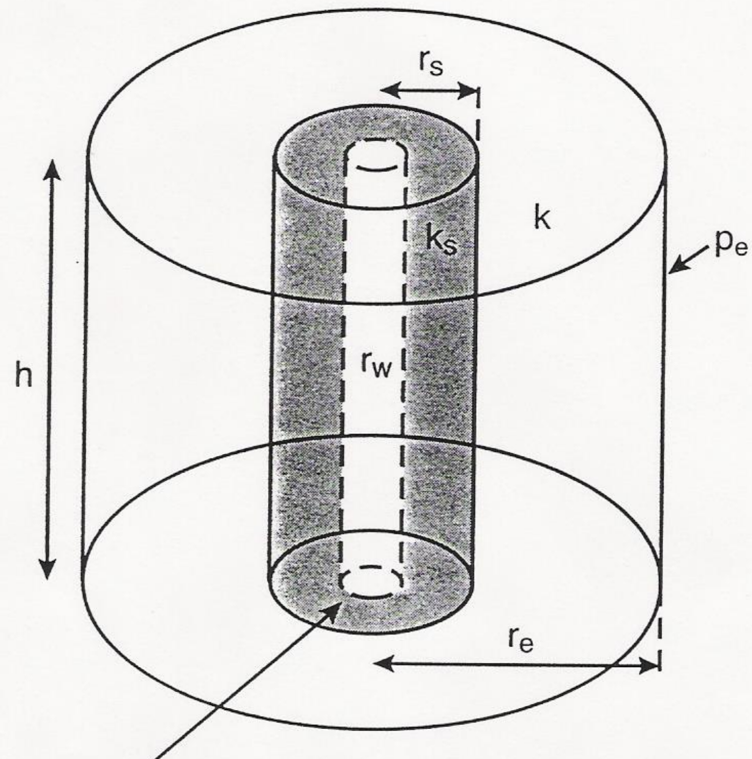
Skin Factor

- A formation damage model is a dynamic relationship expressing the fluid transport capability of porous medium undergoing various alteration processes.

- Modeling formation damage in petroleum reservoirs has been of continuing interest. Although many models have been proposed, these models **do not have the general applicability**.

Hawkins' Formula





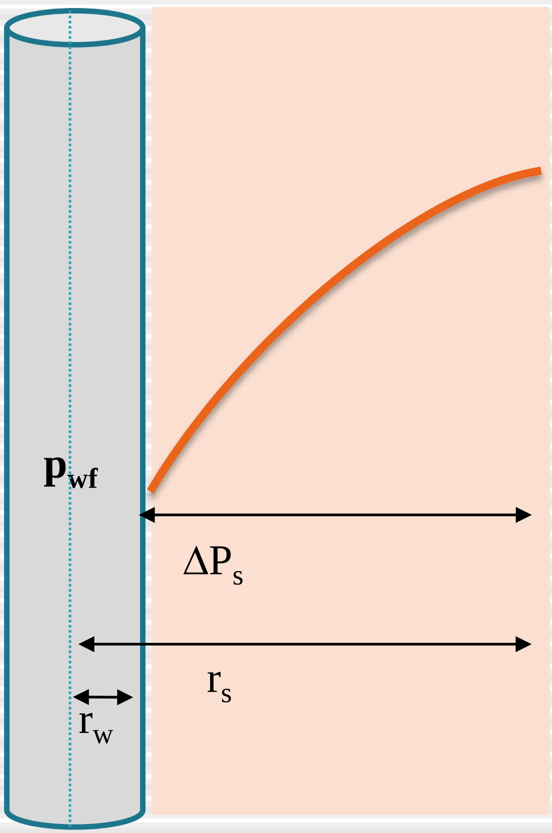
$$\Delta p_s = \Delta p_{real} - \Delta p_{ideal}$$

Hawkins' Formula

$$\Delta p_{real} = p_s - p_{wf,real} = \frac{q\mu}{2\pi k_s h} \ln\left(\frac{r_s}{r_w}\right)$$

$$\Delta p_{ideal} = p_s - p_{wf,ideal} = \frac{q\mu}{2\pi k h} \ln\left(\frac{r_s}{r_w}\right)$$

$$\Delta p_s = \frac{q\mu}{2\pi k h} s$$



Steady-state pressure drop due to skin is given by:

$$\Delta p_s = \Delta p_{real} - \Delta p_{ideal}$$

$$\frac{q\mu}{2\pi k h} s = \frac{q\mu}{2\pi k_s h} \ln\left(\frac{r_s}{r_w}\right) - \frac{q\mu}{2\pi k h} \ln\left(\frac{r_s}{r_w}\right)$$

$$\frac{1}{k} s = \frac{1}{k_s} \ln\left(\frac{r_s}{r_w}\right) - \frac{1}{k} \ln\left(\frac{r_s}{r_w}\right) \longrightarrow \boxed{s = \left(\frac{k}{k_s} - 1\right) \ln\left(\frac{r_s}{r_w}\right)}$$

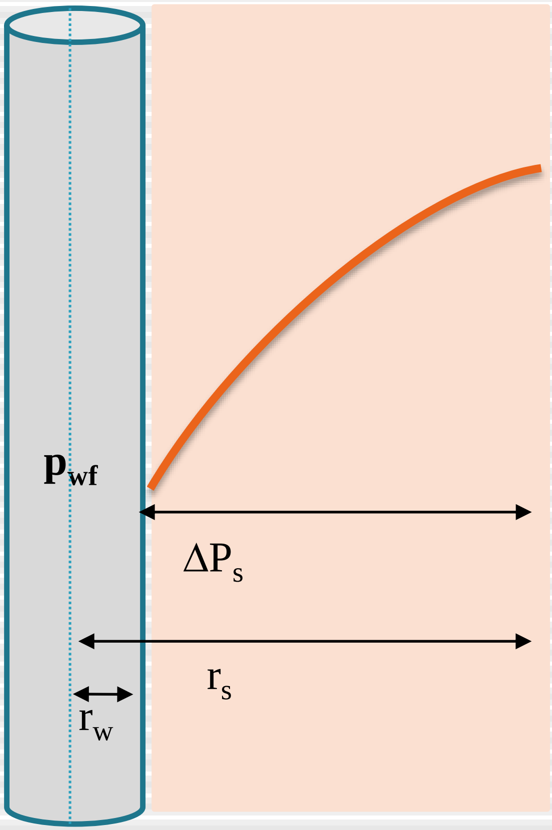
Hawkins' Formula

Hawkins' Formula

$$\Delta p_{real} = \frac{q\mu}{2\pi h}\int_{r_w}^{r_s}\frac{dr}{rk(r)}$$

$$\Delta p_{ideal} = \frac{q\mu}{2\pi kh}\ln\left(\frac{r_s}{r_w}\right)$$

$$\Delta p_s = \frac{q\mu}{2\pi kh}s$$



Steady-state pressure drop due to skin is given by:

$$\Delta p_s = \Delta p_{real} - \Delta p_{ideal}$$

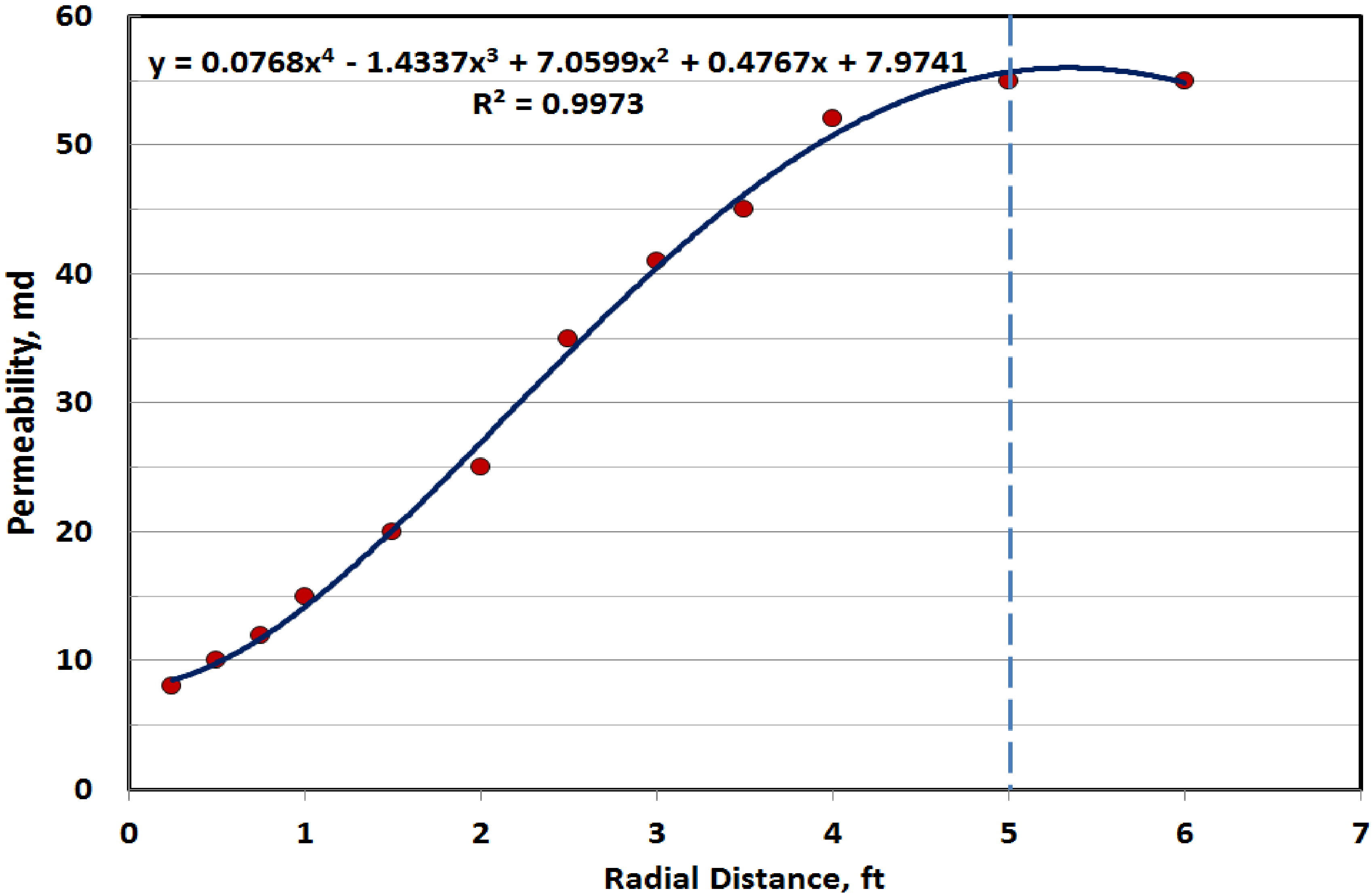
$$\frac{q\mu}{2\pi kh}s = \frac{q\mu}{2\pi h}\int_{r_w}^{r_s}\frac{dr}{rk(r)} - \frac{q\mu}{2\pi kh}\ln\left(\frac{r_s}{r_w}\right)$$

$$\frac{1}{k}s = \int_{r_w}^{r_s}\frac{dr}{rk(r)} - \frac{1}{k}\ln\left(\frac{r_s}{r_w}\right)$$

$$\boxed{s = k\int_{r_w}^{r_s}\frac{dr}{rk(r)} - \ln\left(\frac{r_s}{r_w}\right)}$$

General Hawkins' Formula

Hawkins' Formula - Example



Hawkins' Formula - Example

Example: assume that a well has a radius r_w equal to 0.25 ft, and the damage beyond the well is 5 ft. What would be the skin effect if the permeability impairment results in k/k_s equal to 6 and 12, respectively.

Solution:

$$s = \left(\frac{k}{k_s} - 1\right)\ln\left(\frac{r_s}{r_w}\right) = (6-1)\ln\left(\frac{5.25}{0.25}\right) = 15.22$$

$$s = \left(\frac{k}{k_s} - 1\right)\ln\left(\frac{r_s}{r_w}\right) = (12-1)\ln\left(\frac{5.25}{0.25}\right) = 33.49$$

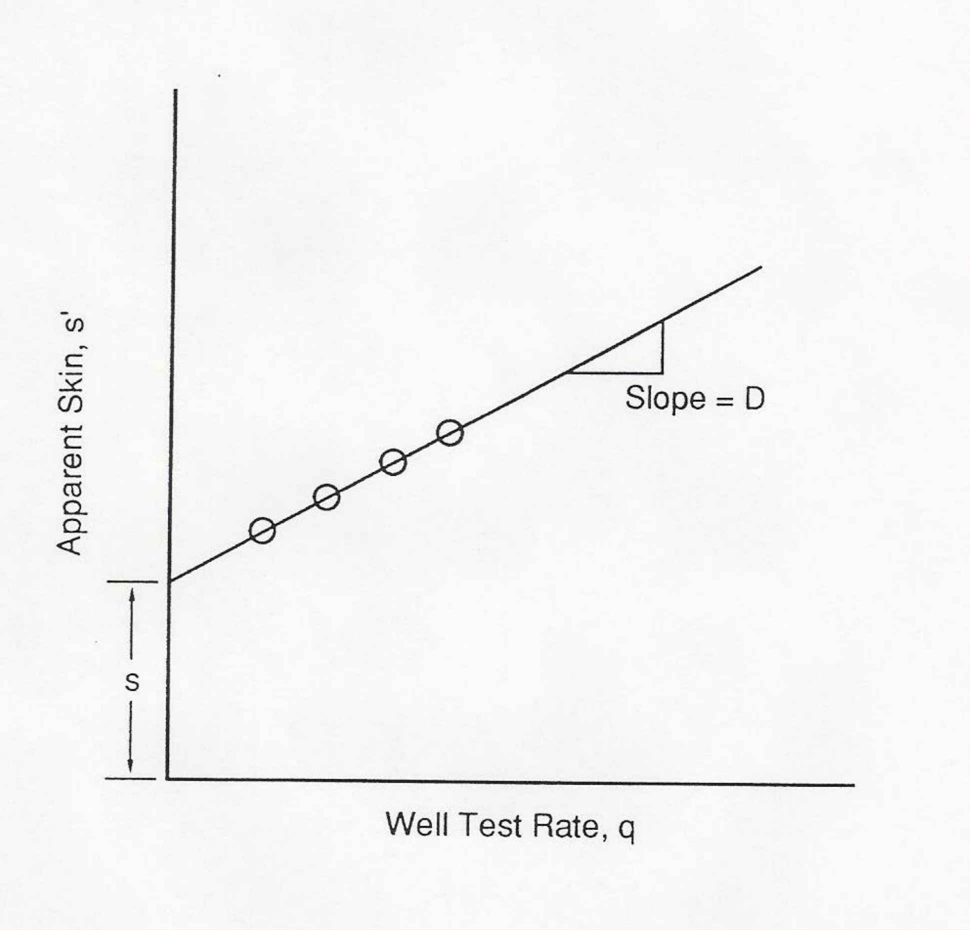
non-Darcy Skin (S')

Skin due to turbulence is additional pressure drop caused by **high gas velocity** near the wellbore and applies only to gas wells.

$$\boxed{s' = Dq}$$

$$D = \frac{6\times10^{-5}\gamma k_s^{-0.1} h}{\mu r_w h_{perf}^2}$$

Where, γ is the gas gravity, k_s is the near-wellbore permeability in md, **h** and h_{perf} are the net and perforated thicknesses in ft and μ is the gas viscosity in cp.



This shows the apparent skin from well testing.

$$\boxed{s' = s + Dq}$$

non-Darcy Skin (S')

Example: Calculate the non-Darcy coefficient for well with wellbore radius of 0.25 ft. Assume that k_s is the same as the reservoir permeability (0.1 md) and h_{perf} is half of the reservoir thickness. Use a viscosity of 0.01 cp, gas gravity of 0.6, and reservoir thickness of 80 ft. What will happen if the near-wellbore permeability reduced by damage to one-fifth?

Solution:

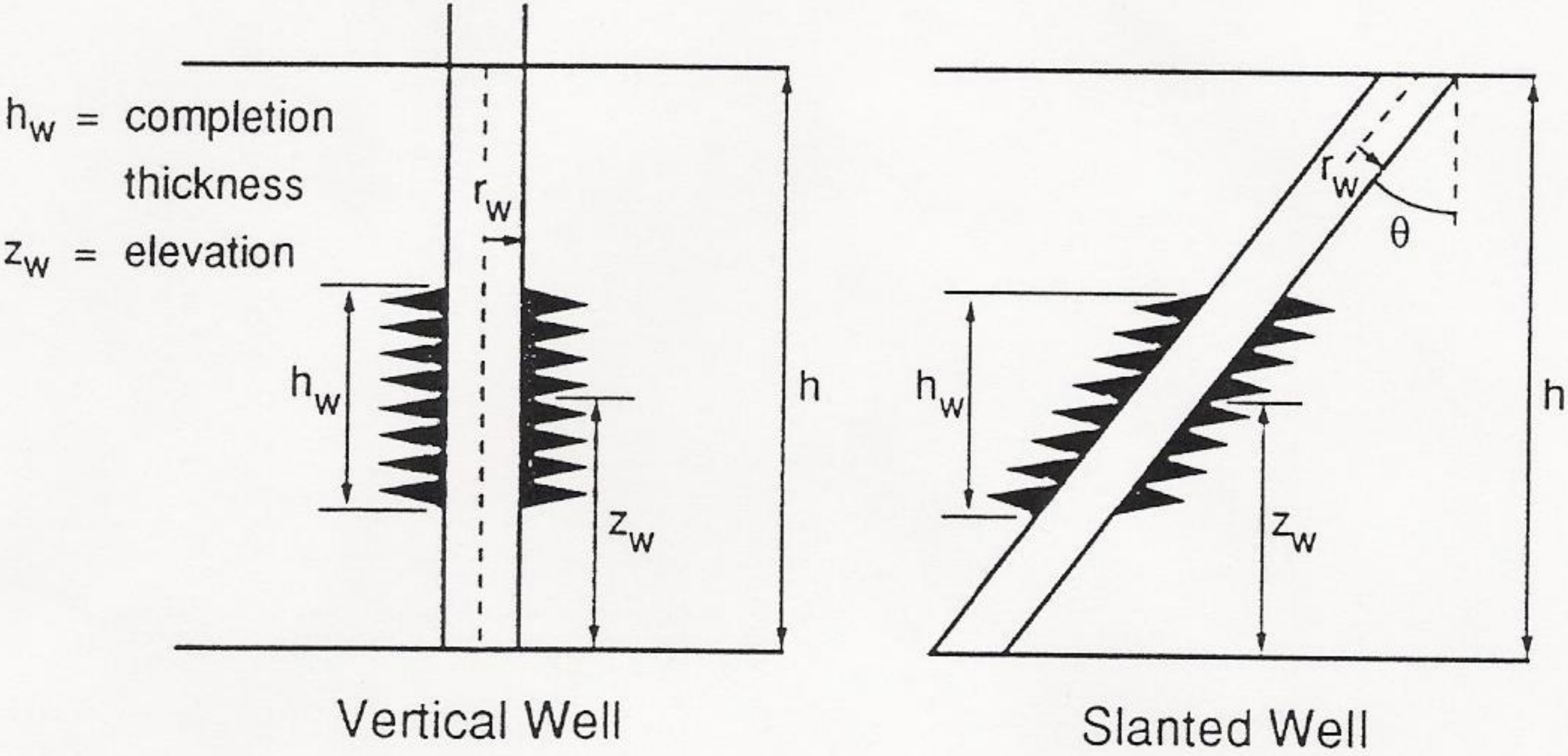
$$D = \frac{6\times10^{-5}\gamma\, k_s^{-0.1} h}{\mu r_w h_{perf}^2} = \frac{6\times10^{-5}(0.6)(0.1)^{-0.1}(80)}{(0.01)(0.25)(40)^2}$$

$$= 9.06\times10^{-9}\ (MSCF/d)^{-1}$$

$$D = \frac{6\times10^{-5}\gamma\, k_s^{-0.1} h}{\mu r_w h_{perf}^2} = \frac{6\times10^{-5}(0.6)(0.02)^{-0.1}(80)}{(0.01)(0.25)(40)^2}$$

$$= 1.06\times10^{-8}\ (MSCF/d)^{-1}$$

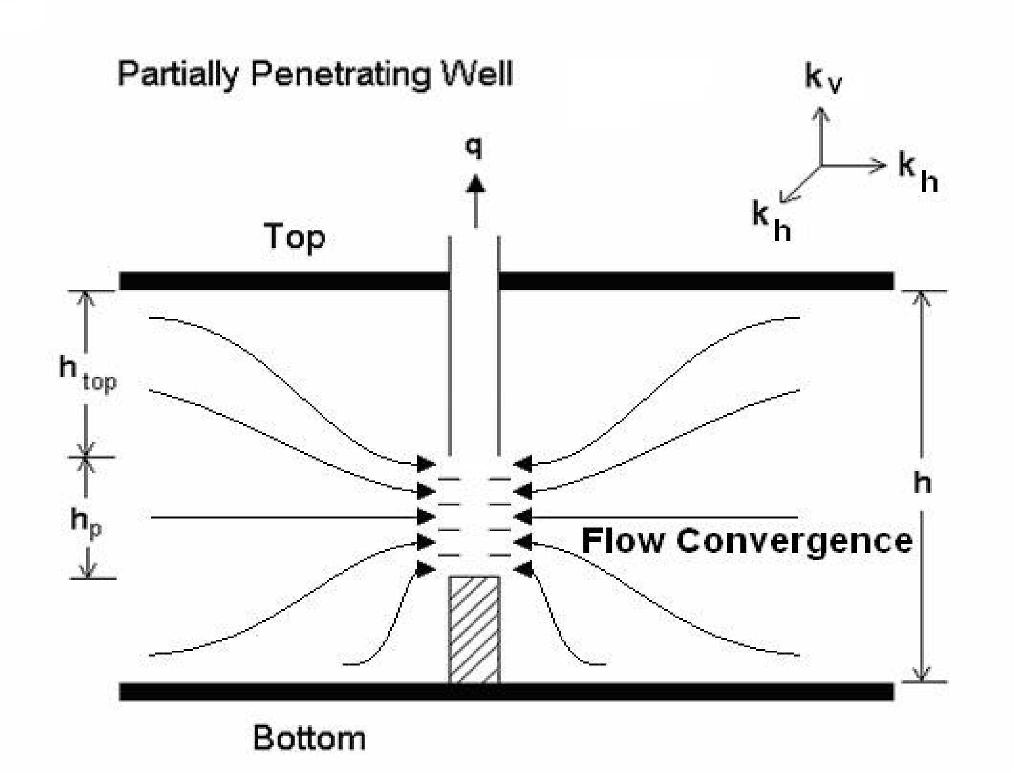
Slanted/Partial Penetration

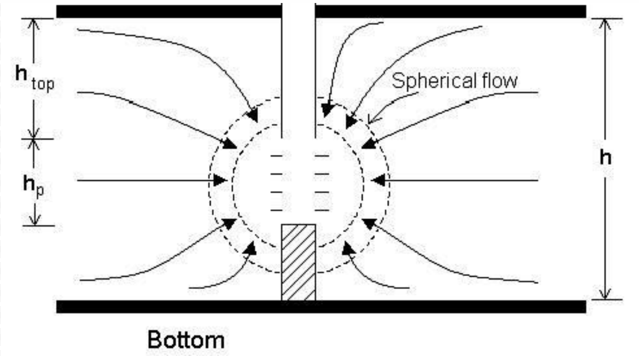


Partial Completion Skin

- Skin due to partial penetration is always greater than 0 and typically ranges from 0 to 30.

- Partial penetration with vertical permeability (k_v) equal to zero is the limiting case. Skin factor can be estimated using Hawkins' formula.

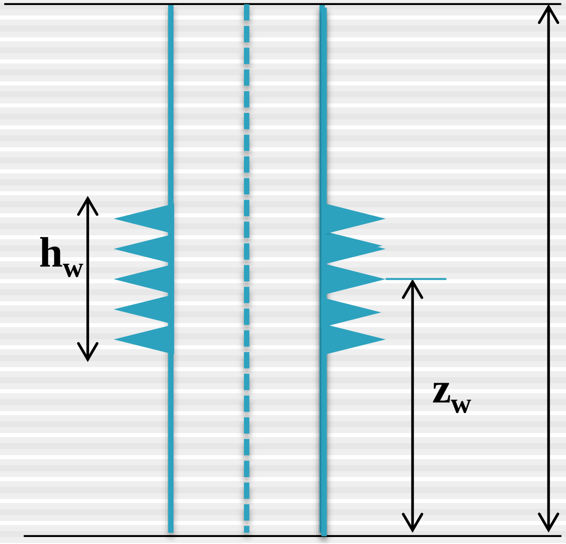




Partial Completion Skin

Muskat's Model

$$s_{pp} = \left(\ln \frac{r_e}{r_w}\right)\left[\frac{1}{\bar{h}\left(1+7\left(\frac{r_w}{h\bar{h}}\right)^{0.5}\cos\left(\frac{\pi\bar{h}}{2}\right)\right)} - 1\right]$$



$$\bar{h} = \left(\frac{h_w}{h}\right)$$ **Completion Ratio**

h = Reservoir height
h_w = Perforation height
z_w = The elevation of the perforation midpoint from the base of the reservoir

This model did not consider the permeability anisotropy

Partial Completion Skin

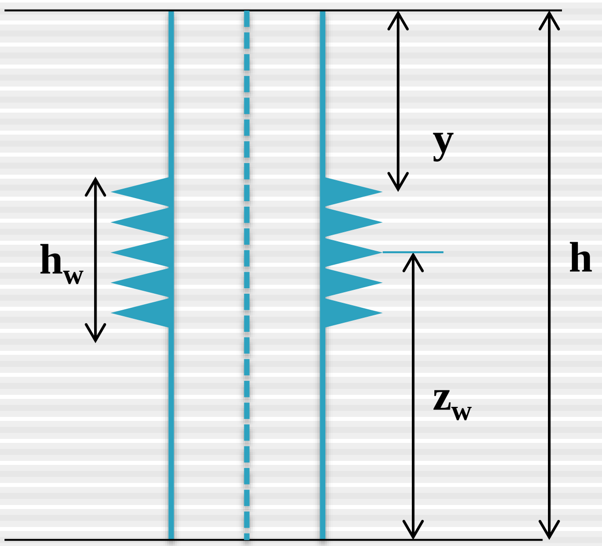
Odeh Model

$$s_{pp} = 1.35\left[\left(\frac{h}{h_w}-1\right)^{0.825}\left(\ln\left(h\sqrt{\frac{k_H}{k_V}}\right)\right)-\left(0.49+0.1\ln\left(h\sqrt{\frac{k_H}{k_V}}\right)\right)\ln\left(r_{wc}\right)-1.95\right]$$

Where,

$$r_{wc} = \begin{cases} r_w \exp\left[0.2126\left(\frac{z_m}{h}\right)+2.753\right] & for\ \ y>0 \\ r_w & for\ \ y=0 \end{cases}$$

$$z_m = y + \left(\frac{h_w}{2}\right)$$



h = Reservoir height
h_w = Perforation height
z_w = The elevation of the perforation midpoint from the base of the reservoir
y = The distance from top of reservoir to top of perforation

Partial Completion Skin

Papatzacos Model

$$s_{pp} = \left(\frac{1}{h_{pD}} - 1\right)\ln\left(\frac{\pi}{2r_D}\right) + \frac{1}{h_{pD}}\left[\frac{h_{pD}}{1+h_{pD}}\left(\frac{A-1}{B-1}\right)^{0.5}\right]$$

Where,

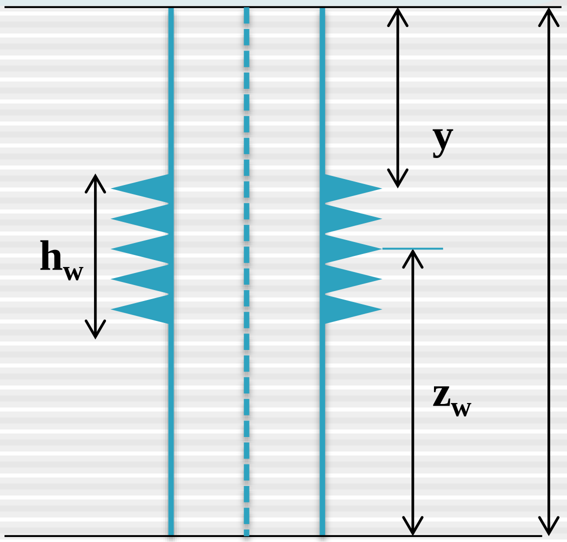
$$h_{pD} = \frac{h_w}{h}$$

$$r_D = \frac{r_w}{h}\left(\frac{k_V}{k_H}\right)^{0.5}$$

$$h_{1D} = \frac{h}{y}$$

$$A = \frac{1}{h_{1D} + \left(h_{pD}/4\right)}$$

$$B = \frac{1}{h_{1D} + \left(3h_{pD}/4\right)}$$



h = Reservoir height

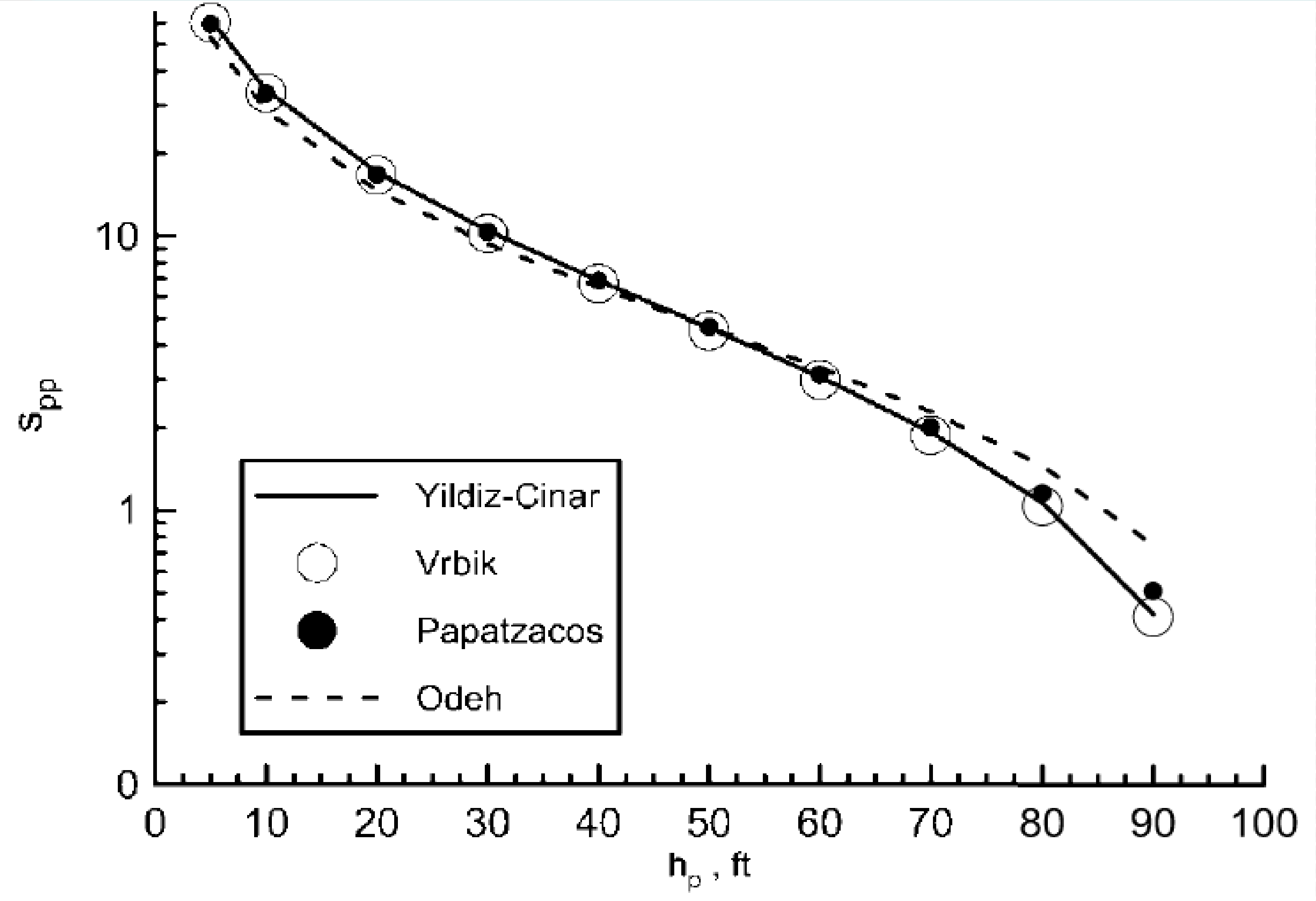
h_w = Perforation height

z_w = The elevation of the perforation midpoint from the base of the reservoir

y = The distance from top of reservoir to top of perforation

All models assumed $k_x = k_y$

Partial Completion Skin



Ref. Yildiz (2006), SPE-82249

Partial Completion Skin

Example:

A well with a radius $r_w = 0.328$ *ft* is completed in a 33-*ft* reservoir. In order to avoid severe water coning problems, only 8 *ft* are completed and the midpoint of the perforations is 29 *ft* above the base of the reservoir.

1. Calculate the skin effect due to partial completion for a vertical well. What would be the composite skin effect if $\Theta = 45°$?
2. Repeat this problem for $h = 330$ *ft*, $h_w = 80$ ft and $z_w = 290$ *ft*.

Partial Completion Skin - Example

Solution:

The dimensionless reservoir thickness h_D is h/r_w = 33/0.328 = 100.

The elevation ratio is z_w/h = 29/33 = 0.875

The completion ratio is h_w/h = 8/33 = 0.25.

From Table 5-1 for a vertical well,

$\Theta = 0^\circ$ and $S_{c+\Theta}$ = 8.6, S_c = 8.6 and S_Θ = 0.

If $\Theta = 45^\circ$, then

S_c = 8.6 but S_Θ = -2.7 resulting in $S_{c+\Theta}$ = 6.

If h_D = 330/0.328 = 1000 and the other ratios are the same.

From Table 5-2

$S_{c+\Theta}$ = 15.7 for the vertical well and

$S_{c+\Theta}$ = 10.4 for the 45° slant well.

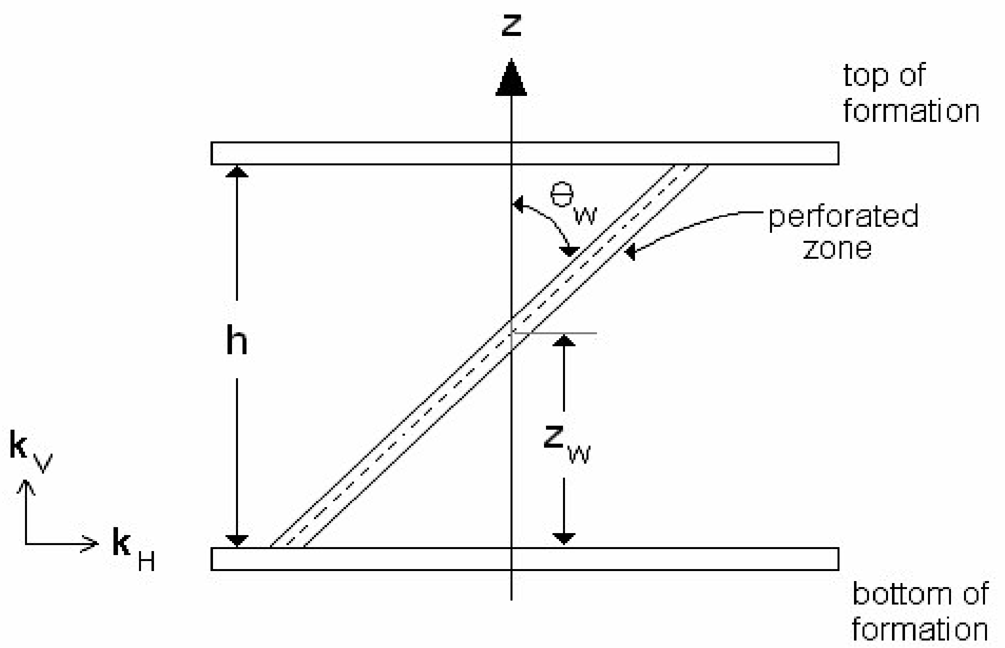
Partial Completion Skin - Example

Solution:

θ	h_D	z_w/h	h_w/h	$S_{\theta+c}$	S_c	S_θ
0	100	0.875	0.25	8.641	8.641	0
15				8.359	8.641	-0.282
30				7.487	8.641	-1.154
45				5.968	8.641	-2.673
60				3.717	8.641	-4.924
75				0.464	8.641	-8.177
0	1000	0.875	0.25	15.733	15.733	0
15				15.136	15.733	-0.597
30				13.344	15.733	-2.389
45				10.366	15.733	-5.367
60				6.183	15.733	-9.550
75				0.632	15.733	-15.101

Skin due to Inclination

- When the angle of inclination through the formation is significant (> 10°), a reduction in pressure drop can occur due to the angle of inclination.
- This pressure drop is defined as skin due to inclination
- The skin is negative and the larger the angle of slant, the larger the negative contribution to the total skin effect.



Inclined Well

$$s_\theta = \left(\frac{\theta_w'}{41}\right)^{2.06} - \left[\left(\frac{\theta'}{56}\right)^{1.865} \cdot \log\left(\frac{h_D}{100}\right)\right]$$

$$\theta_w' = \tan^{-1}\left(\sqrt{\frac{k_H}{k_V}}\tan\theta_w\right)$$

$$h_D = \left(\frac{h}{r_w}\right)\sqrt{\frac{k_H}{k_V}}$$

Does s_θ negative all the time?

Perforation Skin

$$s_p = s_H + s_V + s_{wb}$$

s_H = plane flow effect
s_V = vertical convergence effect
s_{wb} = wellbore effect