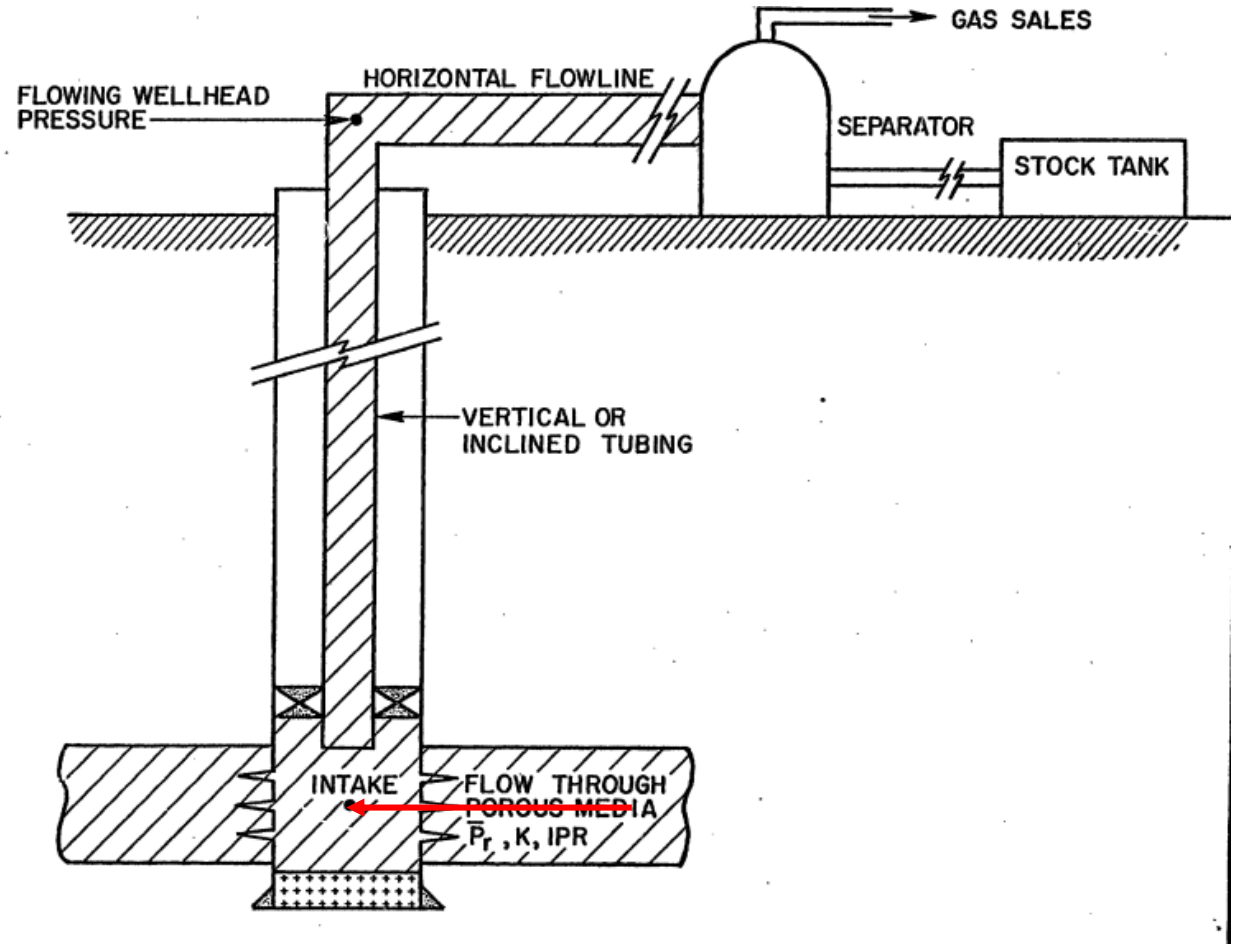
Inflow Performance Relationship (IPR)

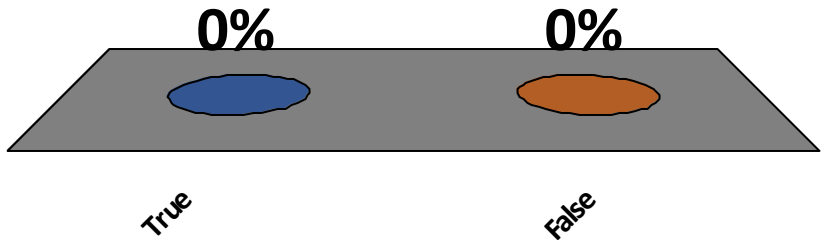
IPR describes flow from the reservoir across the sandface and into the bottom of the well (mid point of perfs)R



Pressure drawdown is ONLY way that a production engineer can control the reservoir flow

1. True
2. False

1 = True , 2 = False

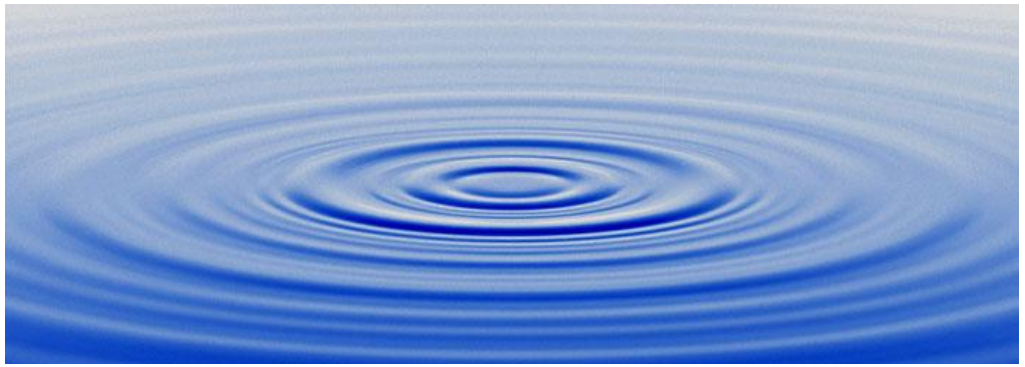


Fluid Flow from Reservoir

- The characteristic of fluid flow can divide to 3 type following time dependent:
  - Steady State Flow
  - Pseudo Steady State Flow
  - Transient Flow

Transient Flow of Undersaturated Oil

- ‘‘Transient flow’’ is defined as a flow regime where/when the radius of pressure wave propagation from wellbore has not reached any boundaries of the reservoir. During transient
- flow, the developing pressure funnel is small relative to the reservoir size. Therefore, the reservoir acts like an infinitively large reservoir from transient pressure analysis point of view.



Transient Flow of Undersaturated Oil

- The equation for pressure drop from fluid flow in transient flow regime of undersatuarated oil reservoir can derive by diffusivity equation and the completed equation in oilfield units show in eq. 2-6 and eq.2-7
- $$P_{wf} = P_i - \frac{162.6q\mu B}{kh}\left(\log t + log\frac{k}{\phi\mu c_t r_w^2} - 3.23\right)$$
- --- eq.2-6
- $$q = \frac{kh(P_i - P_{wf})}{162.6B\mu}\left(\log t + log\frac{k}{\phi\mu c_t r_w^2} - 3.23\right)^{-1}$$

--- eq. 2-7

Example 2-1

Prediction of production rate in an infinite-acting oil well

- Using the well and reservoir variables in Appendix A, develop a production rate profile for 1 year assuming that no boundary effects emerge. Do this in increment of 2 months and use a flowing bottomhole equal to 3500 psi
- Solution: From eq. 2-7 and substitution of the appropriated variables in Appendix A, the well production rate is given by

$$q = \frac{(8.2)(53)(5651-3500)}{(162.)(1.1)(1.7)} \left(\log t + log \frac{8.2}{(0.19)(1.7)(1.29x10^{-5})(0.328)^2} - 3.23\right)^{-1}$$

$$q = \frac{3074}{\log t + 4.03}$$

- For t = 2 months, q = 428 STB/D
- t = 1 year, q = 386 STB/D
- The rate-decline curve for question show in Figure 2-1.

Figure 2-1

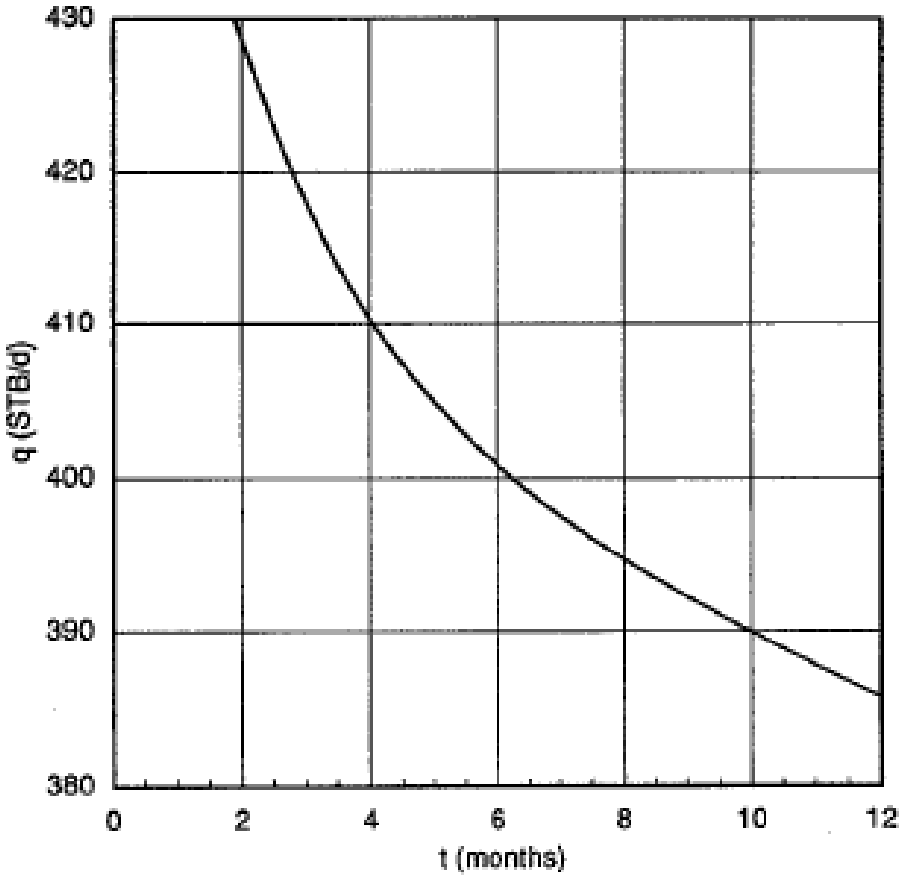


Figure 2-1
Rate decline for an infinite-acting oil reservoir (Example 2-1).

Steady-state flow

- ‘‘Steady-state flow’’ is defined as a flow regime where the pressure at any point in the reservoir remains constant over time. The constant-pressure boundary can be an aquifer or a water injection well. A sketch of the reservoir model is shown in Fig. 2-2,

- Solving eq. 2-9 and including oilfield units and skin effect:
- $$P_e - P_{wf} = \frac{141.2qB\mu}{kh}\left(ln\frac{r_e}{r_w} + s\right)$$
- ------- eq. 2.15
- - The effective wellbore radius (r_w')

$$r_w' = r_w e^{-s}$$

------- eq. 2.18

Productivity Index (J)

$$J = \frac{q}{\bar{p}_r - p_{wf}} = \frac{kh}{141.2B\mu[\ln(\frac{r_e}{r_w}) + s]}$$

------- eq. 2.19

Example 2-2

Steady-state production rate calculation and rate improvement(stimulation)

- Assume that a well in the reservoir described in Appendix A has a drainage area equal to 640 acres (r_e = 2980 ft) and is producing at steady state with an outer boundary(constant) pressure equal to 5651 psi. Calculate the steady-state production rate if the flowing bottomhole pressure is equal to 4500 psi. Use a skin effect equal to +10.

Solution

- From Eq. 2-15 and rearrangement,
- $$q = \frac{(8.2)(53)(5651-4500)}{(141.2)(1.1)(1.7)[\ln\left(\frac{2980}{0.328}\right)+10]} = 100 \text{ STB/D}$$
- To increase the production rate by 50%, one possibility is to increase the drawdown, $P_e - P_{wf}$ by 50%. Therefore

$$(5651 - P_{wf})_2 = 1.5(5651 - 4500)$$

P_{wf} = 3925 psi

A second possibility is to reduce the skin effect. In this case

$$\left(ln\frac{2980}{0.328} + s_2\right) = \left(ln\frac{2980}{0.328} + 10\right)/1.5$$

s = 3.6

Example 2-3

Effect of drainage area on well performance

- Demonstrate the effect of drainage area on oil well production rate by calculating the ratios of production rates from 80-,160-, and 640-acre drainage areas to that obtained from a 40-acre drainage area. The well radius is 0.328 ft

Solution: Example 2-3

- -Assuming that Skin effect is zero,
- - the ratios of the production rates (or productivity index) is
- $$\frac{q}{q_{40}} = \frac{(\ln r_e/r_w)_{40}}{(\ln r_e/r_w)}$$
- And the drainage radius calculated by

$$r_e = \sqrt{\frac{(A)43560}{\pi}}$$

The calculated result show in Table 2-1

Table 2-1

Production Rate Increases (Over a 40-acre spacing)			
A (acres)	r_e (ft)	ln (r_e/r_w)	q/q_{40}
40	745	7.73	1
80	1053	8.07	0.96
160	1489	8.42	0.92
640	2980	9.11	0.85

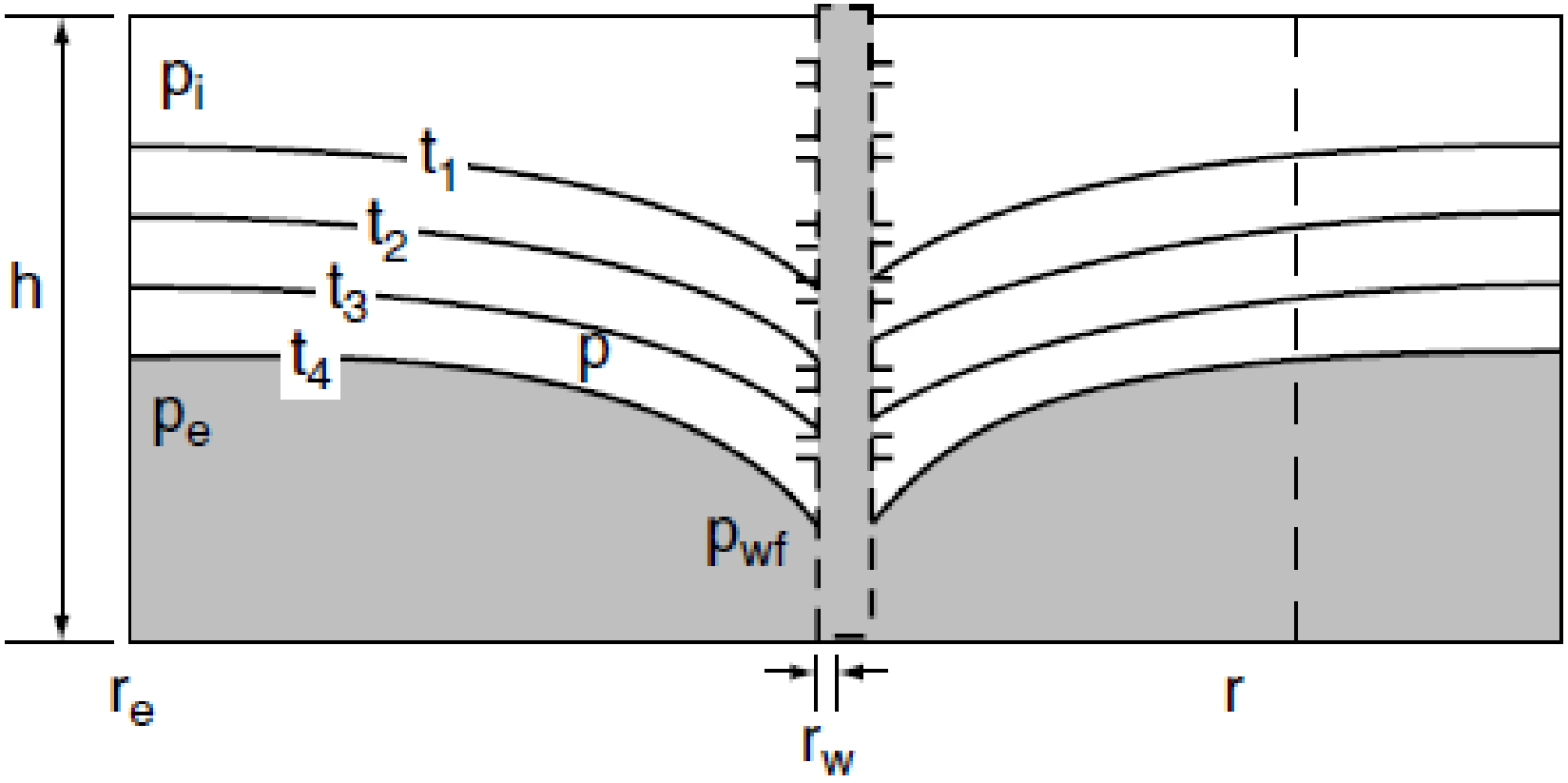
Comments

- The productivity ratios in this example indicate that the drainage area assigned to a well has a small impact on the production rate. For tight reservoirs (< 1mD for oil, <.1 mD for gas) cumulative production differences are even less because transient behavior is evident for much of the time.

Pseudo Steady State Flow

- ‘‘Pseudo–steady-state’’ flow is defined as a flow regime where the pressure at any point in the reservoir declines at the same constant rate over time. A no-flow boundary can be a sealing fault, pinch-out of pay zone, or boundaries of drainage areas of production wells.

A sketch of a reservoir with no-flow boundaries.



Pseudo Steady State Flow

- The equation of pressure drop calculation for Pseudo steady state flow regime show in 2-30.

$$\bar{p} - p_{wf} = \frac{141.2q\mu B}{kh}\left(ln\frac{0.472r_e}{r_w} + s\right)$$

------ eq. 2-30

Transition to Pseudo-steady state from infinite acting behavior.

$$t_{pss} = \frac{\phi\mu c_t A}{0.000264k}t_{DA}$$ ------ eq. 2-34

** t_{DA} value depends on the drainage shape

- If the drainage area can be approximated by a circle with an equivalent drainage radius r_e. ($t_{DA} = 0.1$), the t_{pss} time is:

- $$t_{pss} \approx 1200 \frac{\phi \mu c_t r_e^2}{k}$$

---- eq. 2-35

Wells Drainage Irregular Patterns

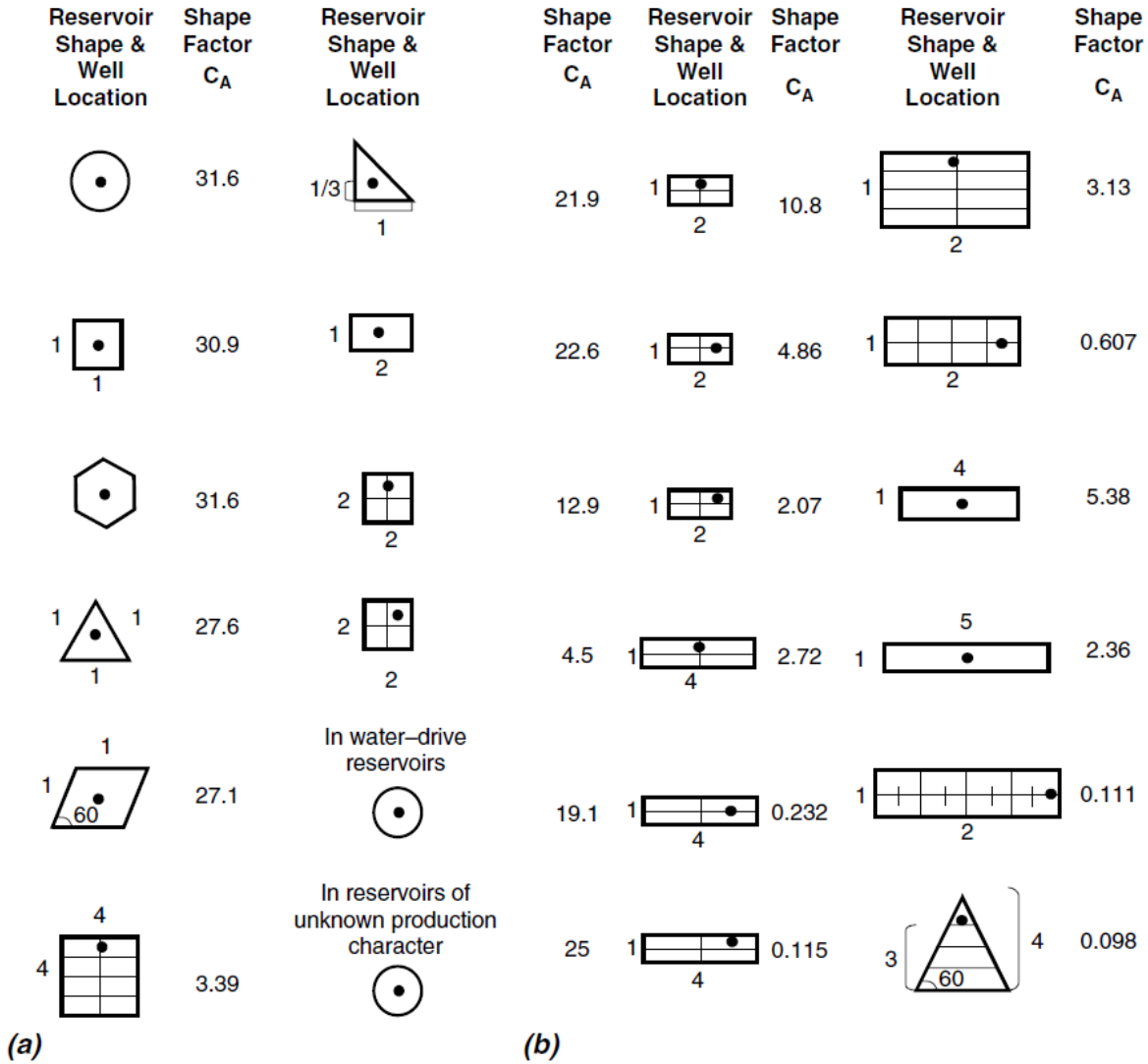
In case of the drainage area have irregular shaped, the pressure drawdown equation show in eq. 2-37.

$$\bar{p} - p_{wf} = \frac{141.2 q \mu B}{kh}\left(\frac{1}{2} ln \frac{4A}{\gamma C_A r_w^2} + s\right)$$

------ eq. 2-37

The term of C_A get from figure 2-3

Figure 2-3


Reservoir Shape & Well Location
Shape Factor C_A
31.6
30.9
31.6
27.6
27.1
3.39
1/3
1
2
60
4
In water–drive reservoirs
In reservoirs of unknown production character
(a)
21.9
22.6
12.9
4.5
19.1
25
10.8
4.86
2.72
0.232
0.115
3.13
0.607
5.38
2.36
0.111
0.098
(b)

Example 2-5
Impact of irregular well

- Assume that two wells in the reservoir described in Appendix A each drain 640 acres. Furthermore, assume that $\bar{p}$ = 5651 psi (same as p_i) and that s = 0. The flowing bottomhole pressure in both is 3500 psi. However, well A is placed at the center of a square whereas well B is at the center of the upper right quadrant of a square drainage shape. Calculate the production rates from the two wells at the onset of pseudo steady state.

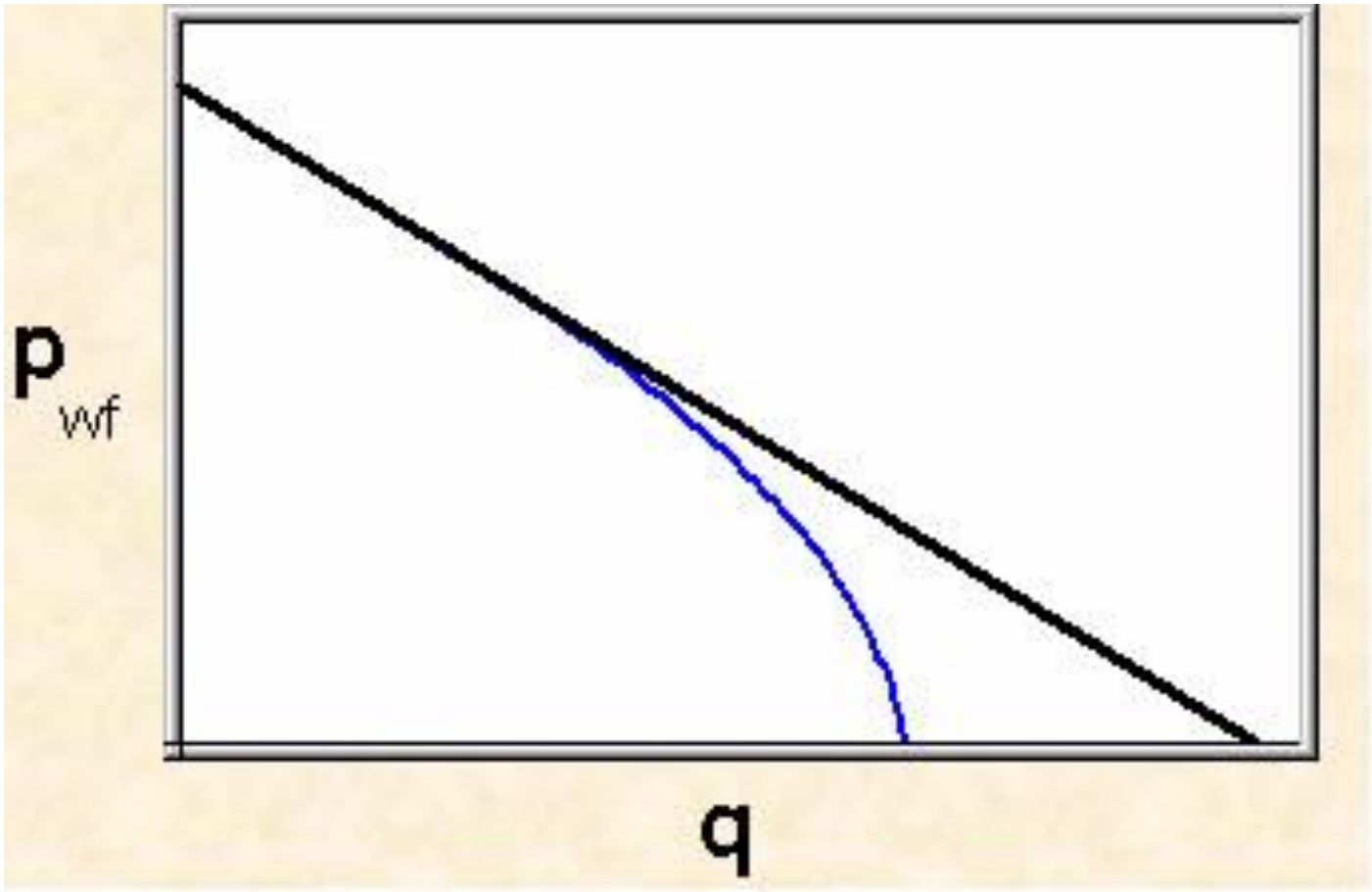
Solution: Example 2-5

- Well A: The shape factor, C_A, from Fig 2-3 is equal to 30.9. Therefore from eq. 2-37
- $q = \frac{(8.2)(53)(2151)}{(141.2)(1.1)(1.7)(0.5)\ln[(4)(640)(43560)/(1.78)(30.9)(0.328)^2}$
- q = 423 STB/D
- Well B: Since it is located at the center of the upper right quadrant. Its shape factor is 4.5
- q = 379 STB/D (a 10% reduction)

Inflow Performance Relationship

- IPR is used for evaluating reservoir deliverability in production engineering. The IPR curve is a graphical presentation of the relation between the flowing bottom-hole pressure and liquid production rate. A typical IPR curve is shown Next Figure.

IPR plot



Inflow Performance Relationship

- The magnitude of the slope of the IPR curve is called the ‘‘productivity index’’ (PI or J), that is,

$$J = \frac{q}{\bar{p}_r - p_{wf}}$$

- Where q = flow rate, STB/D

  J = productivity index, STB/D/psi

  p_r = volumetric average drainage area pressure

  p_{wf} = bottom hole flowing pressure

IPR of each flow regimes

- Transient IPR

$$J = \frac{q}{(P_i - P_{wf})} = \frac{kh}{162.6B\mu}\left(\log t + log\frac{k}{\phi\mu c_t r_w^2} - 3.23\right)^{-1}$$

- Steady state IPR

$$J = \frac{q}{\bar{p}_r - p_{wf}} = \frac{kh}{141.2B\mu[\ln(\frac{r_e}{r_w}) + s]}$$

- Pseudo steady state IPR

$$J = \frac{q}{(\bar{P} - P_{wf})} = \frac{kh}{141.2B\mu[\ln\left(\frac{0.472r_e}{r_w}\right) + S]}$$

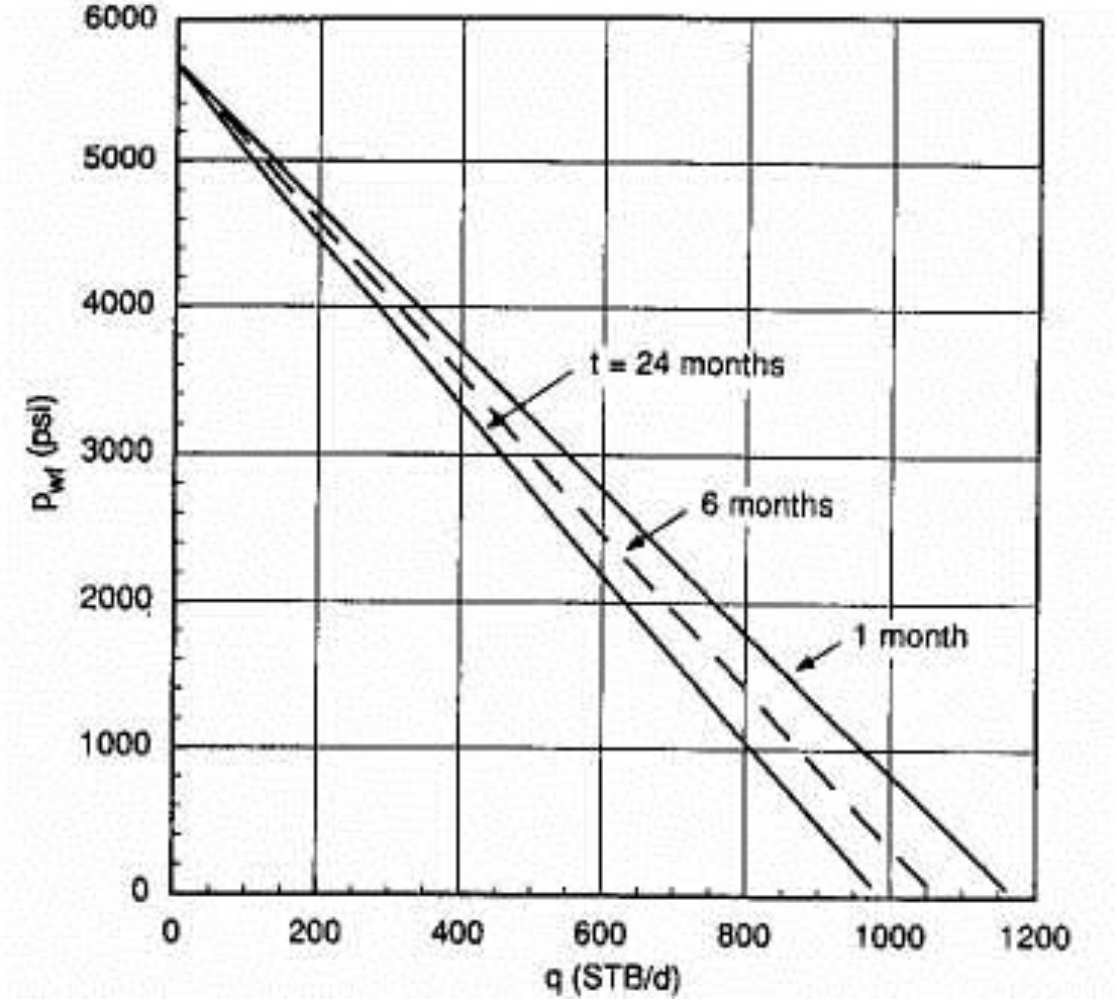
Example 2-7
Transient IPR

- Using the well and reservoir data in Appendix A, construct transient IPR curve for 1,6, and 24 months. Assume zero skins
- Solution: from IPR equation with substituted variables:

$$q = \frac{1.43(5651-p_{wf})}{\log t+4.03}$$

the relationship between q and p_{wf} show in Fig 2-5.

Example 2-7:Transient IPR
Figure 2-5



Example 2-8

Steady-State IPR: Influence of the skin effect

- Assume that the initial reservoir pressure of the well described in Appendix A is also the constant pressure of the outer boundary, p_e (steady state). Draw IPR curve for skin effect equal to 0, 5, 10, and 50 respectively. Use a drainage radius of 2980 ft (A = 640 acres)

Solution: from IPR equation with substituted variables:

$$p_{wf} = 5651 - 5.54q \qquad \text{for s = 0}$$

$$p_{wf} = 5651 - 8.58q \qquad \text{for s = 5}$$

$$p_{wf} = 5651 - 11.6q \qquad \text{for s = 10}$$

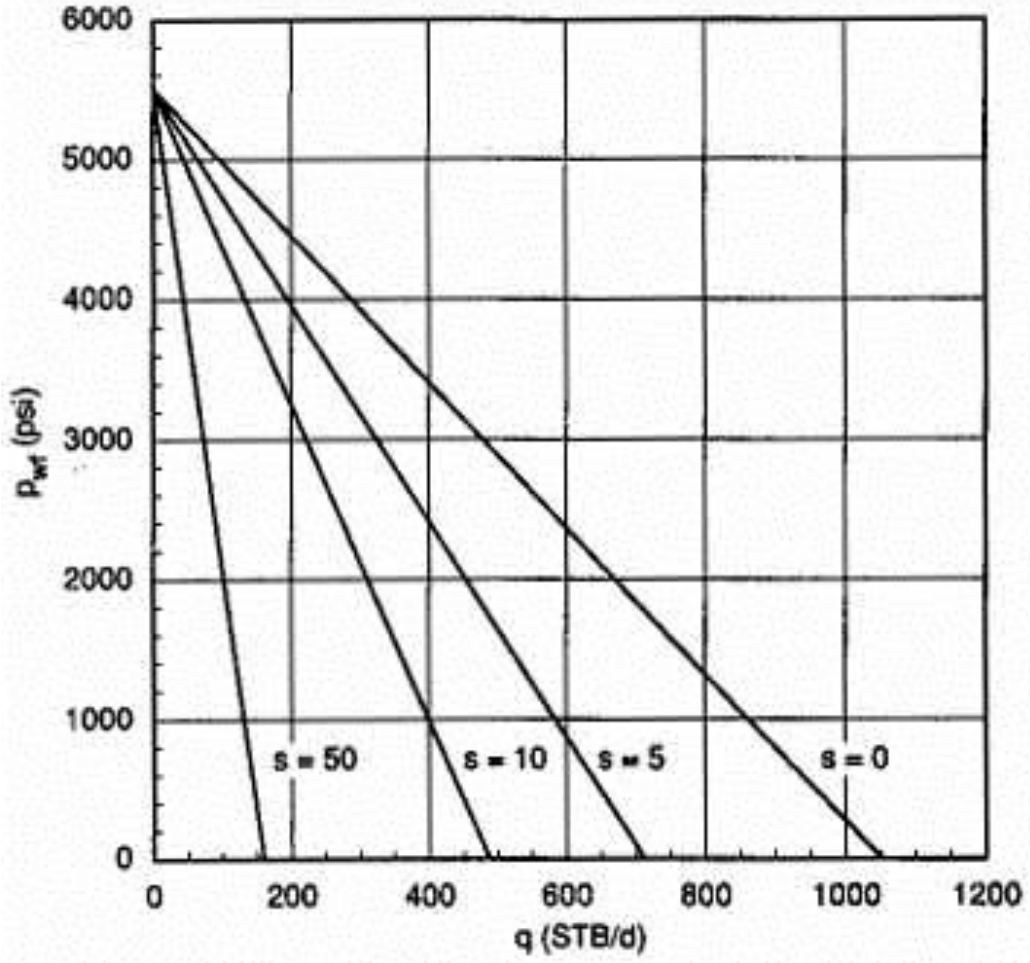
$$p_{wf} = 5651 - 35.9q \qquad \text{for s = 50}$$

the relationship between q and p_{wf} show in Fig 2-6.

Example 2-8

Steady-State IPR: Influence of the skin effect

Figure 2-6



Example 2-9

Pseudo-Steady-State IPR: Influence of average reservoir pressure

- Calculate the IPR curve for zero skin effect but for average reservoir pressure in increments of 500 psi from initial 5651 to 3500 psi. Use all other variables from Appendix A. Drainage radius is 2980 ft.

Solution: from IPR equation with substituted variables:

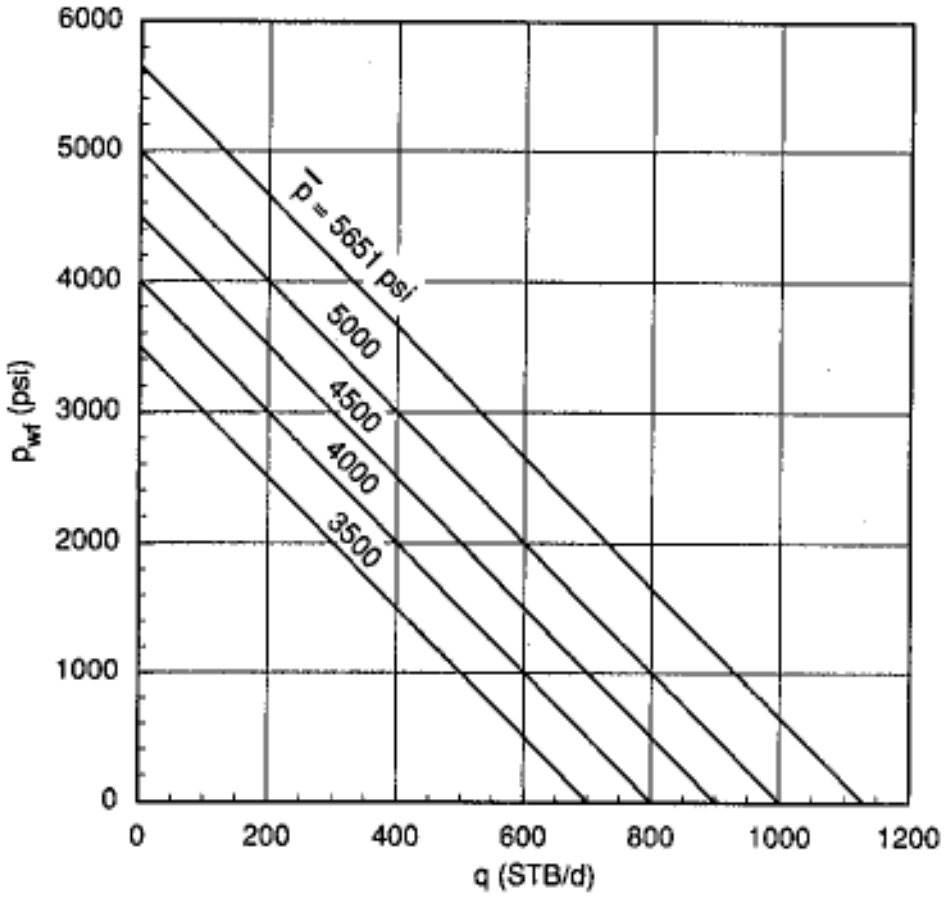
$$p_{wf} = 5651 - 5q$$

For all average reservoir pressure, the figure 2-7 show the IPR curve of this example.

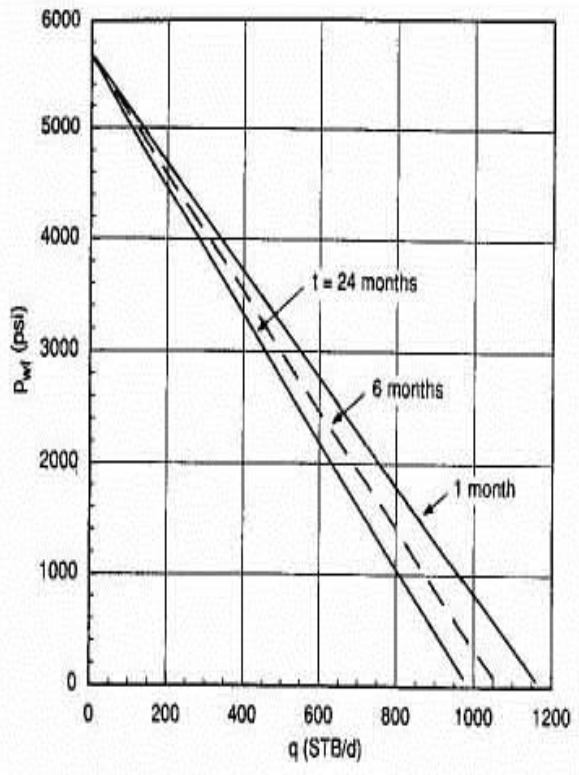
Example 2-9

Pseudo-Steady-State IPR: Influence of average reservoir pressure

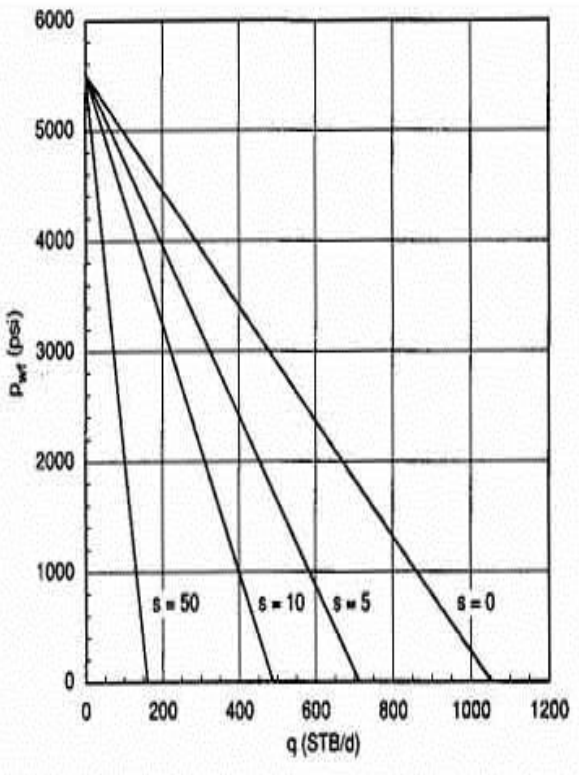
Figure 2-7



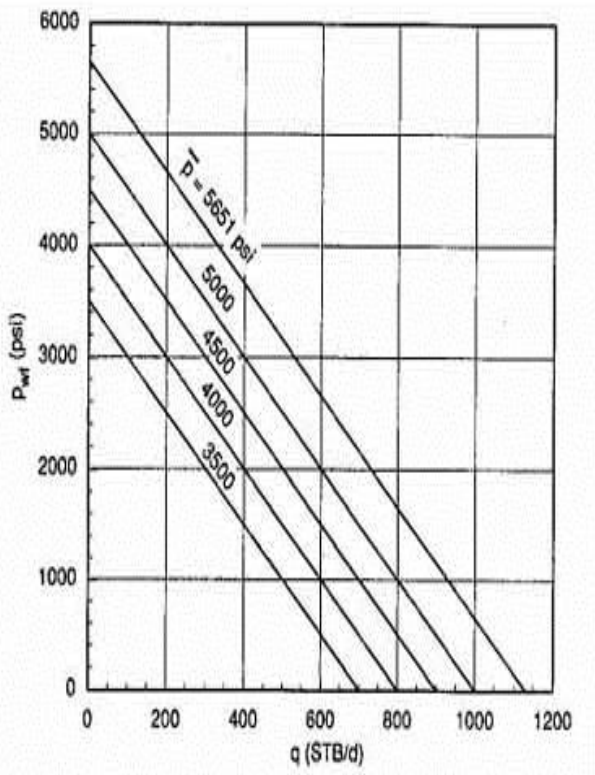
Comparison of IPR for flow regimes type.



Transient IPR



Steady State IPR



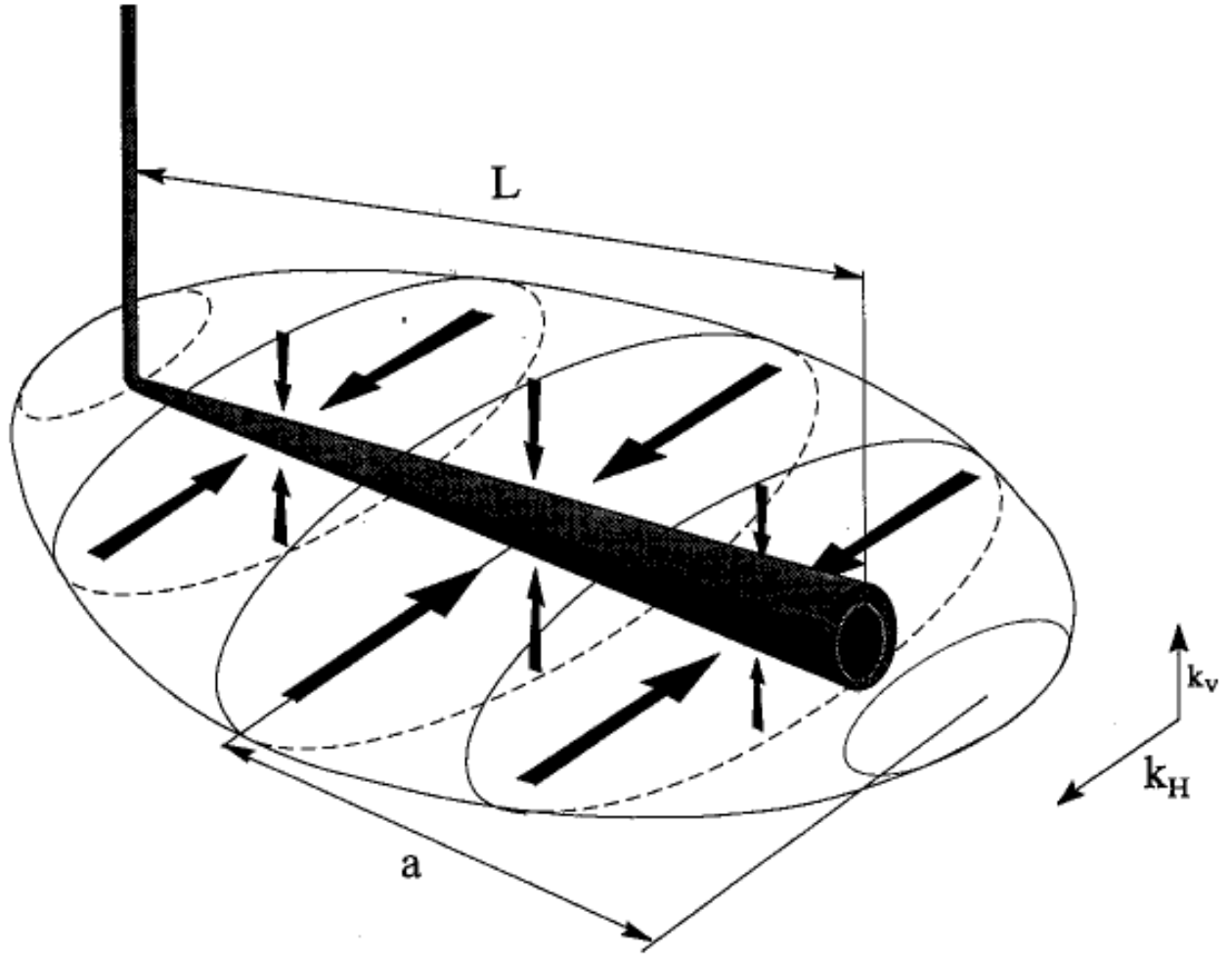
Pseudo-Steady State IPR

Horizontal Well Production

- Since 1980s, Horizontal wells began capturing an ever-increasing share of hydrocarbon production. The horizontal wells are excellent producers for thin reservoir ($h < 50$ ft) or for thicker reservoirs with good vertical permeability (k_V).

- A horizontal well of length L penetrating a reservoir with horizontal permeability k_H and vertical permeability k_V creates a drainage pattern that is different from that a vertical well. The drainage pattern for horizontal well show in Fig. 2-8.
- Of particular importance in the production of the horizontal well is horizontal to vertical permeability anisotropy.

Figure 2-8



Joshi (1988) presented a horizontal well deliverability relationship that augmented by Economides et al.(1990). The relationship (mixed steady state in the horizontal plane and pseudo-steady state in vertical plane) is

- $$q = \frac{k_H h \Delta p}{141.2 B \mu \left(ln\left\{ \frac{\left[a + \sqrt{a^2 - (\frac{L}{2})^2} \right]}{L/2} \right\} + \left(\frac{I_{ani} h}{L} \right) ln \frac{I_{ani} h}{[r_w (I_{ani} + 1)]} \right)}$$ -- eq.2-46

Where I_{ani} is a measurement of vertical-to-horizontal permeability anisotropy and is given by

$$I_{ani} = \sqrt{\frac{k_H}{k_V}}$$ -- eq.2-47

And $$a = \frac{L}{2} \left\{ 0.5 + [0.25 + \left(\frac{r_e H}{\frac{L}{2}} \right)^4]^{0.5} \right\}^{0.5}$$ -- eq. 2-48

Example 2-10

Production rate from a horizontal well: Effect of reservoir thickness and vertical permeability

- Using the variables for the well in Appendix A, calculate the expected production rate from a horizontal well of several lengths up to a maximum length of 2000 ft. Graph length versus production rate. Use r_{eH} = 2980 ft and p_{wf} = 3500 psi.
- Repeat the calculation for reservoir heights equal to 25 and 2250 ft and for k_V equal to 8.2 md (I_{ani} = 1) and 131 md (I_{ani} = 0.25). Also graph the productivity index ratios between these horizontal wells and vertical wells in the same reservoirs.

Solution

- The calculations below are done for a horizontal well of length L, equal to 2000 ft. From Eq. (2-48)

$$a = \frac{2000}{2}\left\{0.5 + \left[0.25 + \left(\frac{2980}{1000}\right)^4\right]^{0.5}\right\}^{0.5}$$

From Eq. 2-46, $I_{ani} = \sqrt{\frac{8.2}{0.9}} = 3$

Then $q = \frac{(8.2)(53)(5651-3500)}{(141.2)(1.1)(1.7)\left(ln\left\{\frac{\left[3065+\sqrt{3065^2-(1000)^2}\right]}{1000}\right\}+\left(\frac{(3)(53)}{2000}\right)ln\frac{(3)(53)}{[(0.328)(3+1)]}\right)}$

q = 1634 STB/D

If I_{ani} = 1 then q = 1862 STB/D; and if I_{ani} = 0.25 then q = 1958 STB/D

Skin effect and effective wellbore radius for a horizontal well

- The equation of Effective wellbore radius for a horizontal well show in Eq. 2-53

$$r_w' = \frac{r_e}{\left\{\left[a+\sqrt{a^2-\left(\frac{L}{2}\right)^2}\right]/\left(\frac{L}{2}\right)\right\}\left[\frac{I_{ani}h}{r_w(I_{ani}+1)}\right]^{\frac{I_{ani}h}{L}}}$$

----Eq. 2-53

- And the horizontal well skin effect is added to eq. 2-46, So the new equation show in eq. 2-54

$$q = \frac{k_H h \Delta p}{141.2B\mu\left(ln\left\{\frac{\left[a+\sqrt{a^2-(\frac{L}{2})^2}\right]}{L/2}\right\}+\left(\frac{I_{ani}h}{L}\right)ln\frac{I_{ani}h}{[r_w(I_{ani}+1)]}+s_{eq}'\right)}$$

----Eq 2-54

- For oil flow rate equation

$$q_o = \frac{k k_{ro} h (p_e - p_{wf})_o}{141.2 B_o \mu_o \left[ln\left({}^{r_e}/_{r_w}\right) + s \right]}$$

------- Eq.2-57

- For water flow rate equation

$$q_w = \frac{k k_{rw} h (p_e - p_{wf})_w}{141.2 B_w \mu_w \left[ln\left({}^{r_e}/_{r_w}\right) + s \right]}$$

------- Eq.2-58

and the relative permeabilities, k_{ro} and k_{rw}, being function of S_w, as shown in Fig 2-11

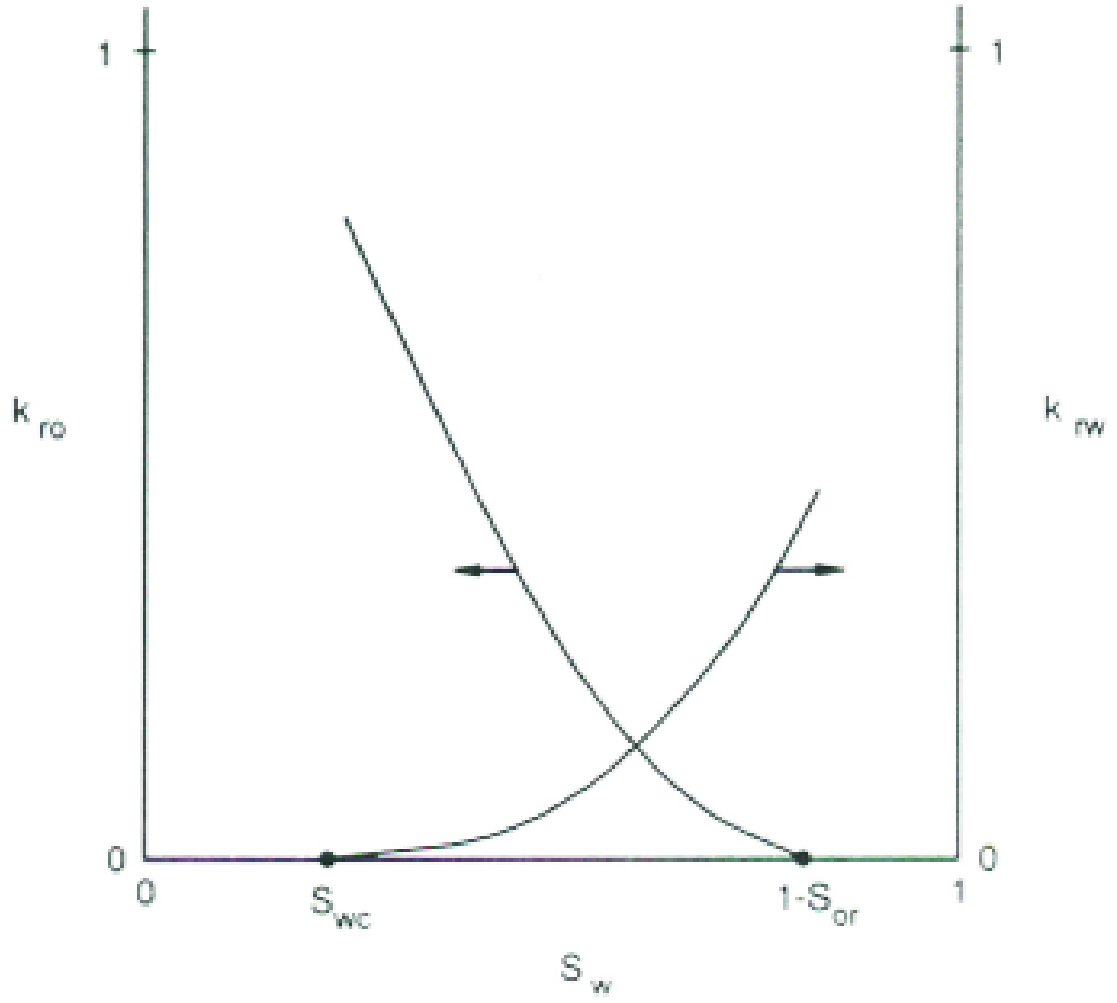



Figure 2-11
Water production: relative permeability effects