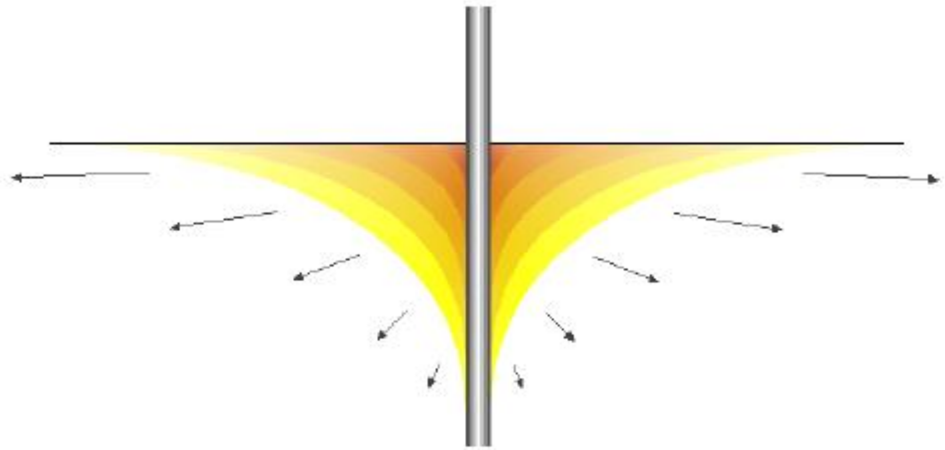
Advanced Pressure Transient Analysis



Well Test Analysis of Hydraulically Fractured Well

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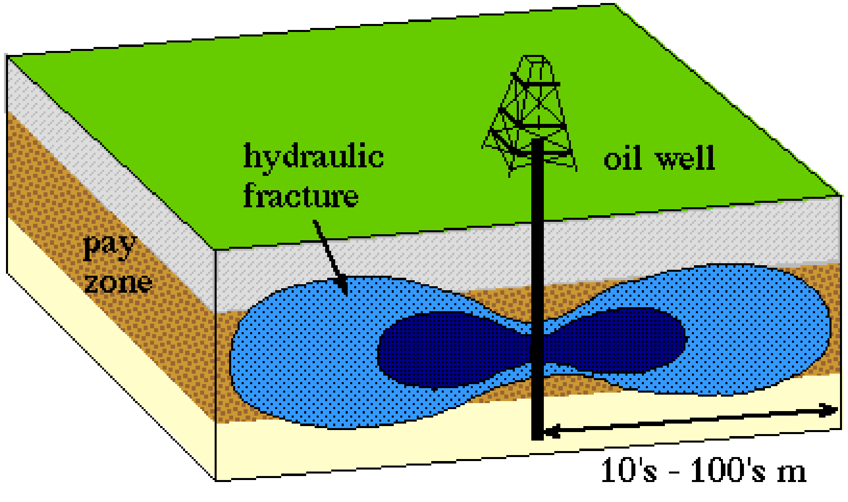
1

Hydraulic Fracturing

❑ Often newly drilled wells do not flow satisfactorily and stimulation is required. A popular and effective stimulation practice is hydraulic fracturing. The objective of this technique is to provide a greatly increased surface for the reservoir fluid to enter the wellbore. In order for this to be effective the pressure drop along the fracture needs to be small, requiring a high fracture conductivity (defined by the product of fracture width and fracture permeability).

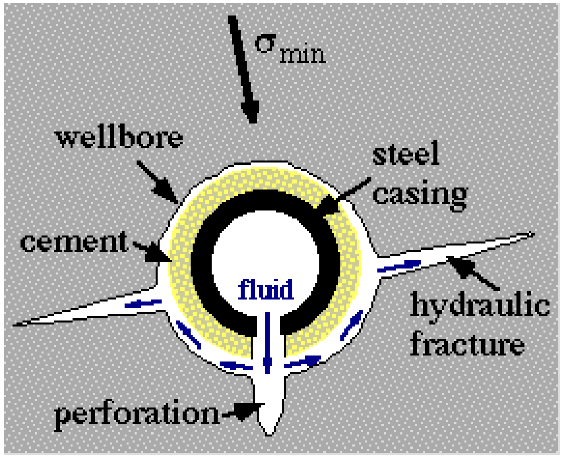
❑ A fracture is defined as a single crack initiated from the wellbore by hydraulic fracturing. It should be noted that fractures are different from “fissures,” which are the formation of natural fractures.

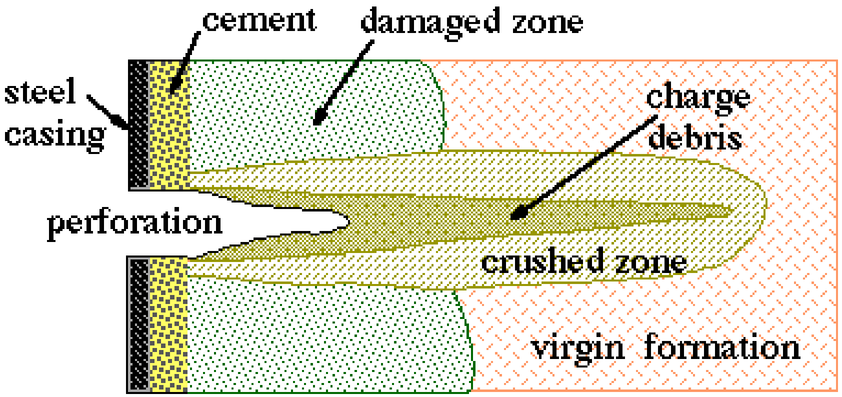


Hydraulic Fracturing

- Massive hydraulic fracturing (MHF) stimulation treatments are extensively used in tight reservoirs to boost the reservoir performance.

- A good fractured well surveillance is essential for optimal reservoir exploitation and long-term strategic plan development.





Depth >3000 ft: It is believed that the hydraulic fracturing results in the formation of vertical fractures.

Depth< 3000 ft: The likelihood is that horizontal fractures will be induced.

Characterization of Hydraulic Fractures

❑The fracture has a much greater permeability than the formation it penetrates; hence it influences the pressure response of a well test significantly.

❑ fracture half-length x_f , ft;
❑ r_{eD}, where $r_{eD} = r_e/x_f$;
❑ fracture height h_f , which is often assumed equal to the formation thickness, ft;
❑ fracture permeability k_f , md;
❑ fracture width w_f , ft;
❑ fracture conductivity F_C, where $F_C = k_f w_f$

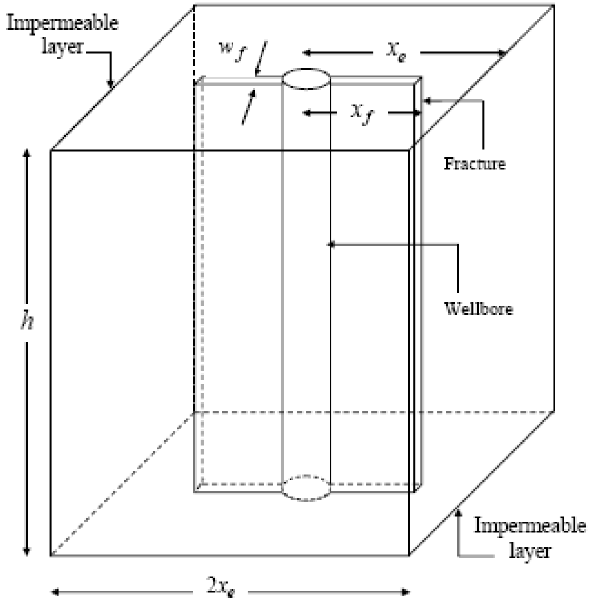


FIGURE 1. Schematic illustration of a vertical fracture in a closed square reservoir

❑The fractured well has unknown geometric features, i.e., x_f , w_f , h_f , and unknown conductivity properties.

Pressure Response in a Hydraulic Fractured Well

- The fracture has a much greater permeability than the formation it penetrates; hence it influences the pressure response of a well test significantly.

- The following dimensionless groups are used when analyzing pressure transient data in a hydraulically fractured well:

Diffusivity group $\eta_{fD} = \dfrac{k_f \phi c_t}{k \phi_f c_{ft}}$ [1.5.19]

Time group $t_{Dx_f} = \left[\dfrac{0.0002637k}{\phi \mu c_t x_f^2}\right] t = t_D \left(\dfrac{r_w^2}{x_f^2}\right)$ [1.5.20]

Conductivity group $F_{CD} = \dfrac{k_f}{k}\dfrac{w_f}{x_f} = \dfrac{F_C}{k x_f}$ [1.5.21]

Storage group $C_{Df} = \dfrac{0.8937C}{\phi c_t h x_f^2}$ [1.5.22]

Pressure group $p_D = \dfrac{kh\,\Delta p}{141.2QB\mu}$ for oil [1.5.23]

Fracture group $r_{eD} = \dfrac{r_e}{x_f}$

where:

x_f = fracture half-length, ft
w_f = fracture width, ft
k_f = fracture permeability, md
k = pre-frac formation permeability, md
t_{Dx_f} = dimensionless time based on the fracture half-length x_f
t = flowing time in drawdown, Δt or Δt_e in buildup, hours
T = Temperature, °R
F_C = fracture conductivity, md ft
F_{CD} = dimensionless fracture conductivity
η = hydraulic diffusivity
c_{ft} = total compressibility of the fracture, psi^{-1}

Test	*Pressure*	*Time*
Drawdown	$\Delta p = p_i - p_{wf}$	t
Buildup	$\Delta p = p_{ws} - p_{wf\ \text{at}\ \Delta t=0}$	Δt or Δt_e

Hydraulic Fractures Models

- Gringarten et al. (1974) and Cinco and Samaniego (1981), among others, proposed three transient flow models to consider when analyzing transient pressure data from vertically fractured wells. These are:

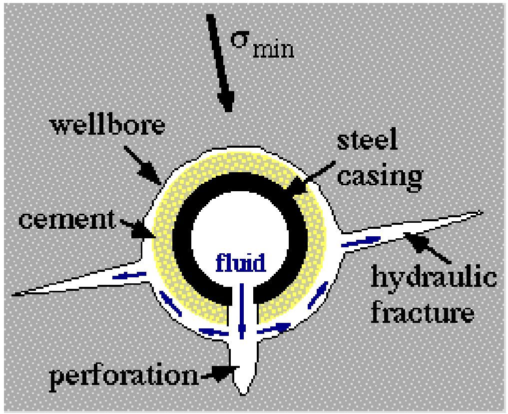
(1) infinite conductivity vertical fractures: A very high conductivity, which for all practical purposes can be considered as infinite (No significant pressure drop from the tip of the fracture to the wellbore)

(2) finite conductivity vertical fractures: These are very long fractures created by massive hydraulic fracture (MHF). These types of fractures need large quantities of propping agent to keep them open and, as a result, the fracture permeability k_f is reduced as compared to that of the infinite conductivity fractures.

Hydraulic Fractures Models

(3) uniform flux fractures.

- A uniform flux fracture is one in which the reservoir fluid flow rate from the formation into the fracture is uniform along the entire fracture length.
- This model is similar to the infinite conductivity vertical fracture in several aspects. The difference between these two systems occurs at the boundary of the fracture. The system is characterized by a variable pressure along the fracture.



Flow Periods for Vertically Fractured Well

- Several flow regimes are observed in fractured wells. One of the responsibilities of the well test analyst is to use the appropriate tools to predict the type of flow regime that may develop in the fracture around the wellbore.

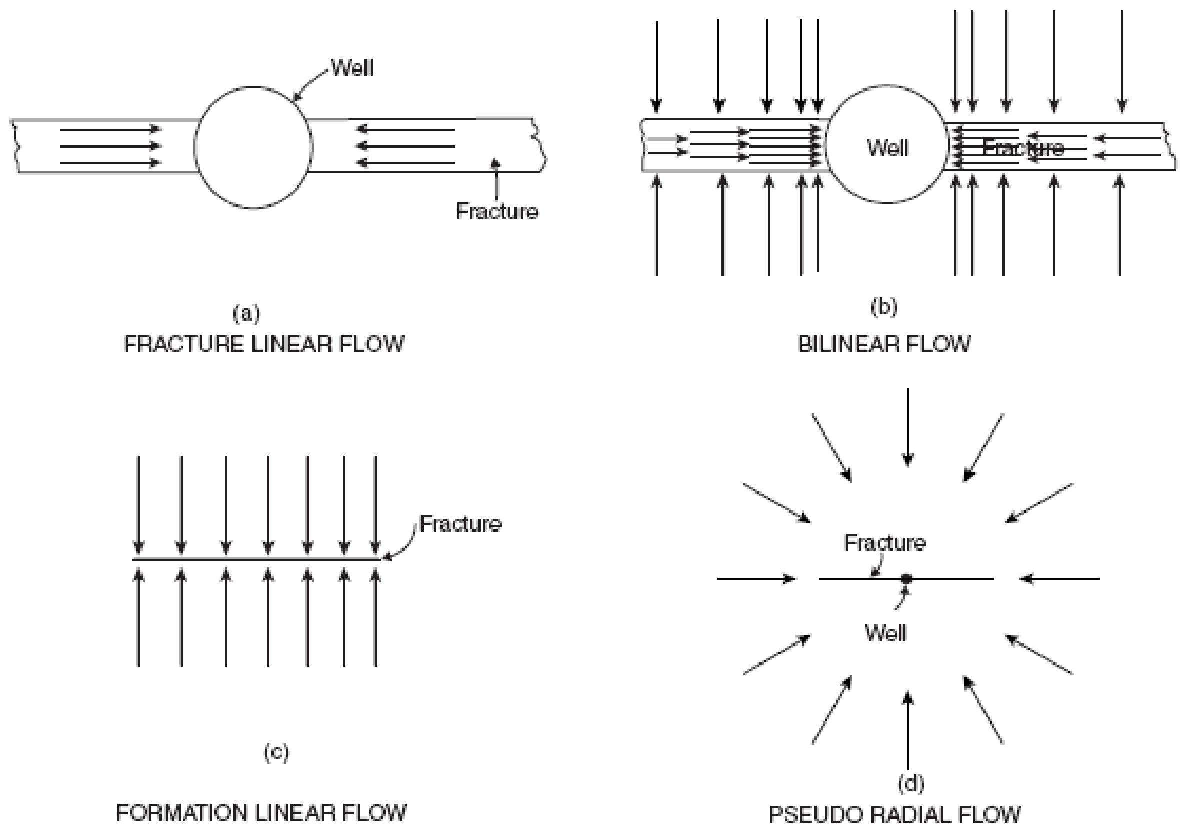
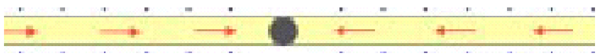


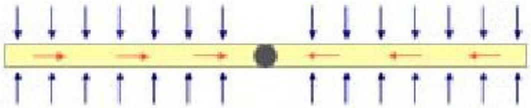
Figure 1.71 Flow periods for a vertically fractured well (After Cinco and Samaniego, JPT, 1981).

Hydraulic Fractures Flow Periods

(1) infinite conductivity vertical fractures;

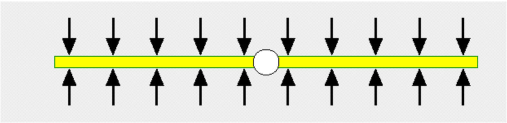
1. fracture linear flow period;
2. formation linear flow period;
3. infinite-acting pseudo-radial flow period.





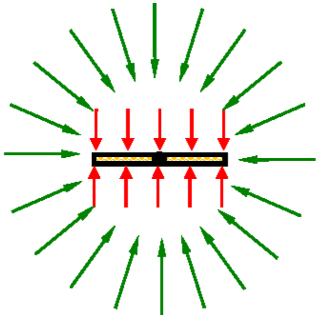
(2) finite conductivity vertical fractures;

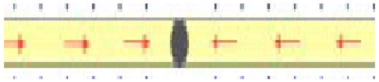
1. initially “linear flow within the fracture”;
2. followed by “bilinear flow”;
3. then “linear flow in the formation”; and
4. eventually “infinite acting pseudo-radial flow.”



(3) uniform flux fractures.

1. linear flow;
2. infinite-acting pseudo-radial flow.





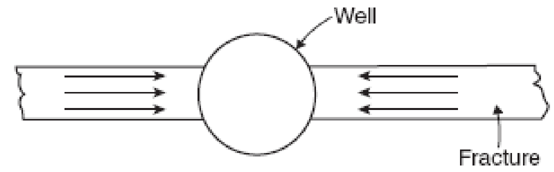
Fracture Linear Flow

- The first flow period, there is negligible fluid coming from the formation, flow within the fracture during this time period is linear.
- The flow in this period can be described by the linear diffusivity equation and is applied to both the fracture linear flow and formation linear flow periods.
- The pressure transient test data during the linear flow period can be analyzed with a graph of p vs $(\text{time})^{0.5}$
- Unfortunately, the fracture linear flow occurs at very early time to be of practical use in well test analysis.
- The fracture linear flow exists for fractures with $F_{CD} > 300$.
- The duration of the fracture linear flow period is short, as it often is in finite conductivity fractures with $F_{CD} < 300$, and care must be taken not to misinterpret the early pressure data.
- In some situations the linear flow straight line is not recognized from well test analysis due to the skin effects or wellbore storage effects.
- End of fracture linear flow can be estimated from the following relation.

Fracture Linear Flow

$$t_{Dx_f} \approx \frac{0.01(F_{CD})^2}{(\eta_{fD})^2}$$

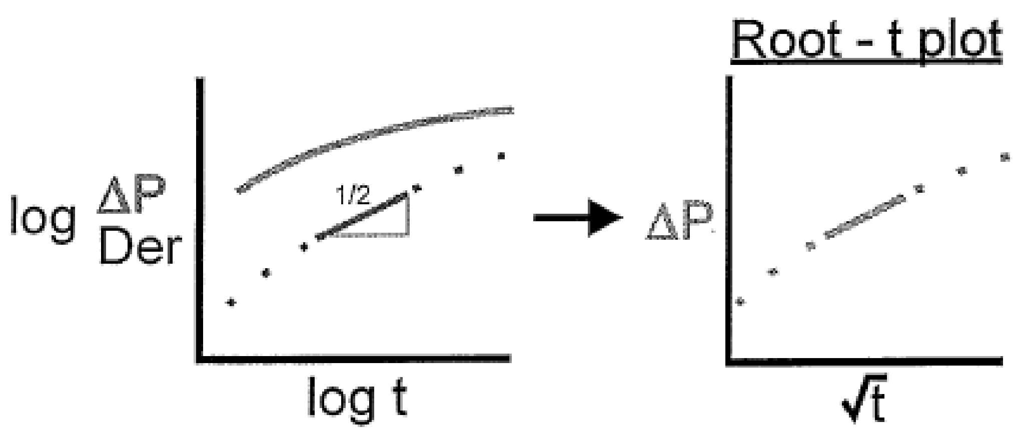
$$\eta_{fD} = \frac{k_f \phi c_t}{k \phi_f c_{ft}}$$

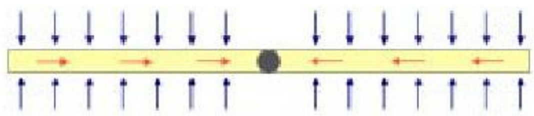


(a)
FRACTURE LINEAR FLOW

$$\text{Conductivity group} \quad F_{CD} = \frac{k_f}{k}\frac{w_f}{x_f} = \frac{F_C}{kx_f} \qquad [1.5.21]$$

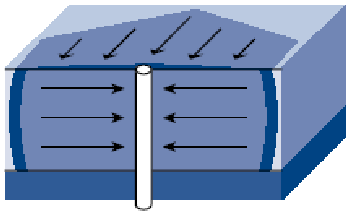
$\Delta P \; \alpha \; \sqrt{t}$





Bilinear flow

- The pressure drop through the fracture is significant for the finite conductivity case and the bilinear flow behavior is observed; however, the infinite conductivity case does not exhibit bilinear flow behavior because the pressure drop in the fracture is negligible.
- Two types of linear flow occur simultaneously.
- One flow is a linear incompressible flow within the fracture and the other is a linear incompressible flow in the formation.
- Most of the fluid which enters the wellbore during this flow period comes from the formation.
- Fracture tip effects do not affect well behavior during bilinear flow and, accordingly, it will not be possible to determine the fracture length from the well bilinear flow period data.
- The actual value of the fracture conductivity F_C can be determined during this flow period.

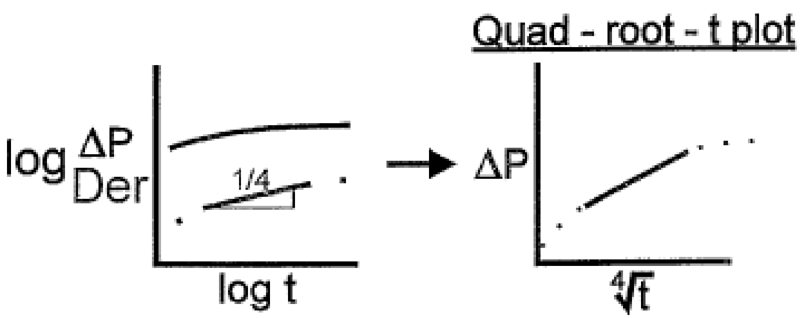


Estimation Fracture Conductivity

$$p_D = \left[\frac{2.451}{\sqrt{F_{CD}}}\right](t_{Dx_f})^{1/4} \Rightarrow \log(p_D) = \log\left[\frac{2.451}{\sqrt{F_{CD}}}\right] + \frac{1}{4}\log(t_{Dx_f})$$

$$\Delta p = \left[\frac{44.1QB\mu}{h\sqrt{F_C}(\phi\mu c_t k)^{1/4}}\right]t^{1/4} \Rightarrow \begin{cases} \Delta p = m_{bf}t^{1/4} \\ m_{bf} = \left[\frac{44.1QB\mu}{h\sqrt{F_C}(\phi\mu c_t k)^{1/4}}\right] \\ F_C = k_f w_f \end{cases}$$

$\Delta P \; \alpha \; \sqrt[4]{t}$

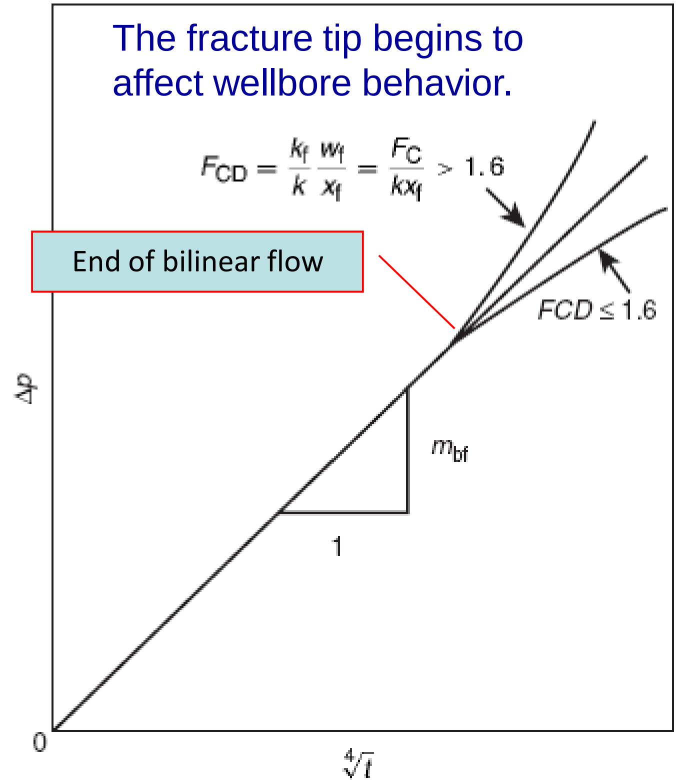


❑When the bilinear flow ends, the plot will exhibit curvature which could concave upwards or downwards depending upon the value of the dimensionless fracture conductivity F_{CD}

❑If the test is not run sufficiently long for bilinear flow to end when F_{CD} > 1.6, it is **NOT** possible to determine <u>the length of the fracture</u>.

❑F_{CD} < 1.6, curvature concave downward, it indicates that the fluid flow *in the reservoir* has changed from a predominantly one-dimensional linear flow to a two-dimensional flow regime.

❑F_{CD} > 1.6, curvature concave upward, fracture tip begins to affect wellbore behavior. If the test is **not** run sufficiently long for bilinear flow to end when F_{CD} > 1.6, *it is not possible to determine the length of* the fracture.



$$F_{CD} = \frac{194.9 QB\mu}{kh\Delta p_{ebf}}$$

$$x_f = \frac{F_C}{F_{CD}k}$$

Q = flow rate, STB/day or Mscf/day
T = temperature, °R

Estimation Fracture Conductivity

Cinco and Samaniego pointed out that the dimensionless fracture conductivity *FCD can be estimated from the bilinear* flow straight line, i.e., ***p** vs.* ***(time)**$^{1/4}$, by reading the value* of the pressure difference *p at which the line ends* p_{ebf} and applying the following approximation:

For oil $\quad F_{CD} = \dfrac{194.9 Q B \mu}{kh \Delta p_{ebf}}$

For gas $\quad F_{CD} = \dfrac{1965.1 Q T}{kh \Delta m(p)_{ebf}}$

where:

Q = flow rate, STB/day or Mscf/day
T = temperature, °R

The end of the bilinear flow, "t_{ebf}," straight line depends on the fracture conductivity and can be estimated from the following relationships (Cinco and Samaniego; 1981):

For $F_{CD} > 3 \qquad t_{Debf} \simeq \dfrac{0.1}{(F_{CD})^2}$

For $1.6 \le F_{CD} \le 3 \qquad t_{Debf} \simeq 0.0205[F_{CD} - 1.5]^{-1.53}$

For $F_{CD} \le 1.6 \qquad t_{Debf} \simeq \left[\dfrac{4.55}{\sqrt{F_{CD}}} - 2.5\right]^{-4}$

Bilinear Flow Equations Oil &Gas

Test	*Pressure*	*Time*
Drawdown	$\Delta p = p_{\mathrm{i}} - p_{\mathrm{wf}}$	t
Buildup	$\Delta p = p_{\mathrm{ws}} - p_{\mathrm{wf\ at\ } \Delta t=0}$	Δt or Δt_{e}

For oil $$F_{\mathrm{C}} = (k_{\mathrm{f}} w_{\mathrm{f}}) = \left[\frac{44.1 QB\mu}{m_{\mathrm{bf}} h (\phi \mu c_{\mathrm{t}} k)^{1/4}}\right]^2$$

For gas $$F_{\mathrm{C}} = (k_{\mathrm{f}} w_{\mathrm{f}}) = \left[\frac{444.6 QT}{m_{\mathrm{bf}} h (\phi \mu c_{\mathrm{t}} k)^{1/4}}\right]^2$$

For oil $$F_{\mathrm{CD}} = \frac{194.9 QB\mu}{kh \Delta p_{\mathrm{ebf}}}$$

For gas $$F_{\mathrm{CD}} = \frac{1965.1 QT}{kh \Delta m(p)_{\mathrm{ebf}}}$$

$$\Rightarrow \quad x_{\mathrm{f}} = \frac{F_{\mathrm{C}}}{F_{\mathrm{CD}} k}$$

Example 1.36 A buildup test was conducted on a fractured well producing from a tight gas reservoir. The following reservoir and well parameters are available:

$Q = 7350$ Mscf/day,	$t_p = 2640$ hours
$h = 118$ ft,	$\phi = 0.10$
$k = 0.025$ md,	$\mu = 0.0252$
$T = 690°$R,	$c_t = 0.129 \times 10^{-3}$ psi^{-1}
$p_{\text{wf at } \Delta t=0} = 1320$ psia,	$r_w = 0.28$ ft

The graphical presentation of the buildup data is given in terms of the log–log plot of $\Delta m(p)$ vs. $(\Delta t)^{1/4}$, as shown in Figure 1.73.

Calculate the fracture and reservoir parameters by performing conventional well testing analysis.

Solution

Step 1. From the plot of $\Delta m(p)$ vs. $(\Delta t)^{1/4}$, in Figure 1.73, determine:

$$m_{\mathrm{bf}} = 1.6 \times 10^8 \ \mathrm{psi^2/cphr^{1/4}}$$

$$t_{\mathrm{sbf}} \approx 0.35 \text{ hours (start of bilinear flow)}$$

$$t_{\mathrm{ebf}} \approx 2.5 \text{ hours (end of bilinear flow)}$$

$$\Delta m(p)_{\mathrm{ebf}} \approx 2.05 \times 10^8 \ \mathrm{psi^2/cp}$$

Step 2. Perform the bilinear flow analysis, as follows:

- Using Equation 1.5.34, calculate fracture conductivity F_{C}:

$$F_{\mathrm{C}} = \left[\frac{444.6QT}{m_{\mathrm{bf}} h (\phi \mu c_{\mathrm{t}} k)^{1/4}}\right]^2$$

$$= \left[\frac{444.6(7350)(690)}{(1.62\times 10^8)(118)[(0.1)(0.0252)(0.129\times 10^{-3})(0.025)]^{1/4}}\right]^2$$

$$= 154 \text{ md ft}$$

- Calculate the dimensionless conductivity F_{CD} by using Equation 1.5.36:

$$F_{\mathrm{CD}} = \frac{1965.1QT}{kh\,\Delta m(p)_{\mathrm{ebf}}}$$

$$= \frac{1965.1(7350)(690)}{(0.025)(118)(2.02 \times 10^{8})} = 16.7$$

- Estimate the fracture half-length from Equation 1.5.21:

$$x_{\mathrm{f}} = \frac{F_{\mathrm{C}}}{F_{\mathrm{CD}}k}$$

$$= \frac{154}{(16.7)(0.025)} = 368 \text{ ft}$$

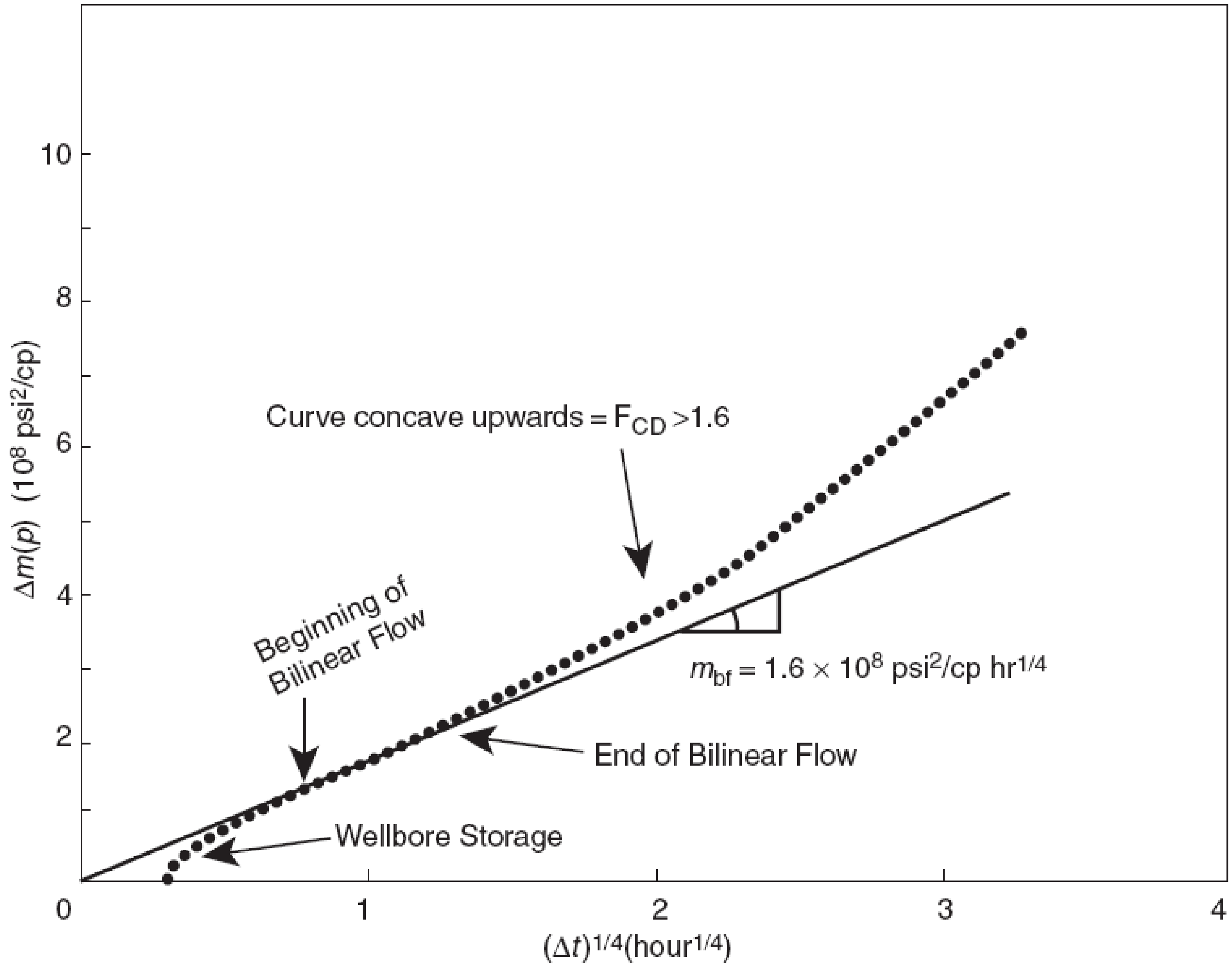
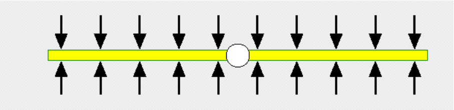
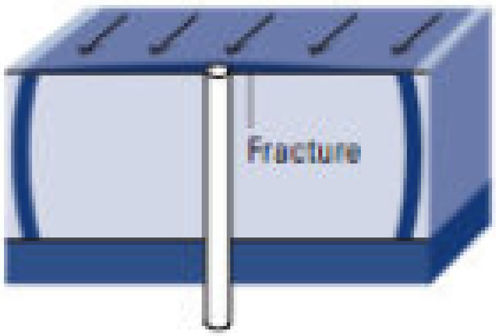


Figure 1.73 *Bilinear flow graph for data of Example 1.36 (After Sabet, M. A.* Well Test Analysis *1991, Gulf Publishing Company).*



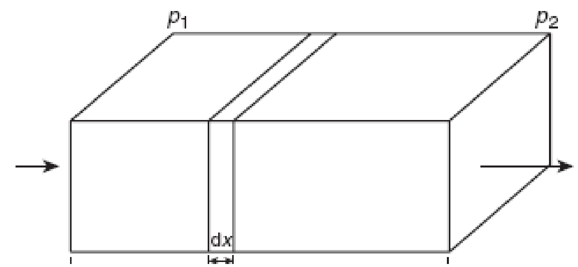
Formation linear flow

- At the end of the bilinear flow, there is a transition period after which the fracture tips begin to affect the pressure behavior at the wellbore and a linear flow period might develop.
- This linear flow period is exhibited by vertical fractures whose dimensionless conductivity is greater that 300, i.e., $F_{CD} > 300$.
- As in the case of fracture linear flow, the formation linear flow pressure data collected during this period is a function of the fracture length x_f and fracture conductivity F_C.
- The pressure behavior during this linear flow period can be described by the diffusivity equation as expressed in linear form:



Formation linear flow

$$\frac{\partial^2 p}{\partial x^2} = \frac{\phi \mu c_t}{0.002637k} \frac{\partial p}{\partial t}$$



For oil fractured wells $\Delta p = \left[\frac{4.064QB}{hx_f} \sqrt{\frac{\mu}{k\phi c_t}} \right] t^{1/2}$

or in simplified form as $\Delta p = m_{vf} \sqrt{t}$

For gas fractured wells $\Delta m(p) = \left[\frac{40.925QT}{hx_f} \sqrt{\frac{1}{k\phi \mu c_t}} \right] t^{1/2}$

or equivalently as $\Delta m(p) = m_{vf} \sqrt{t}$

Formation Linear Flow

Oil fractured well $$x_f = \left[\frac{4.064QB}{m_{vf}h}\right]\sqrt{\frac{\mu}{k\phi c_t}} \qquad [1.5.37]$$

Gas fractured well $$x_f = \left[\frac{40.925QT}{m_{vf}h}\right]\sqrt{\frac{1}{k\phi\mu c_t}} \qquad [1.5.38]$$

where:

Q = flow rate, STB/day or Mscf/day
T = temperature, °R
m_{vf} = slope, psi/$\sqrt{\text{hr}}$ or psi^2/cp$\sqrt{\text{hr}}$
k = permeability, md
c_t = total compressibility, psi^{-1}

The beginning of formation linear flow, "blf," depends on F_{CD} *and can be approximated* from the following relationship:

$$t_{Dblf} \approx \frac{100}{(F_{CD})^2}$$

The end of this linear flow period, "elf," occurs at approximately:

$$t_{Dblf} \approx 0.016$$

Formation Linear Flow

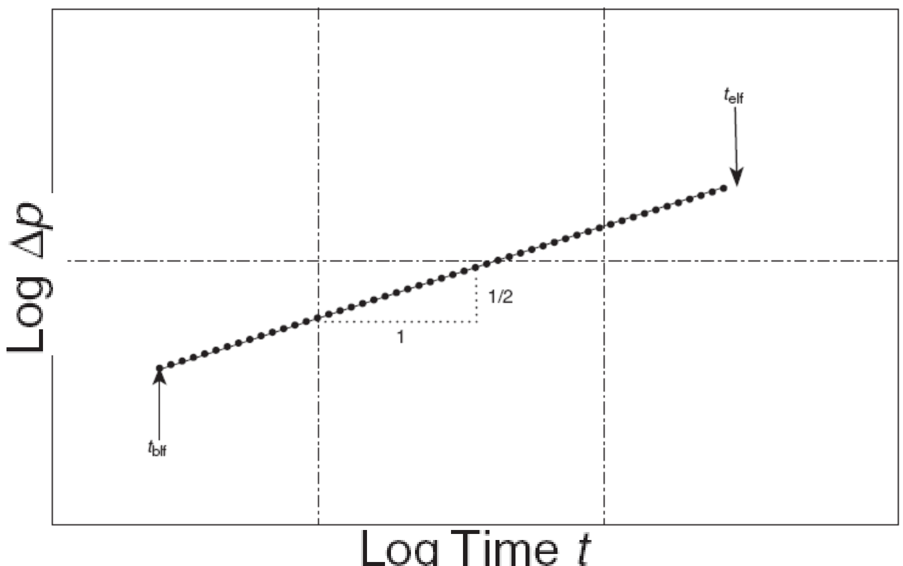


Figure 1.74 *Pressure data for a $\frac{1}{2}$-slope straight line in a log–log graph (After Cinco and Samaniego, 1981).*

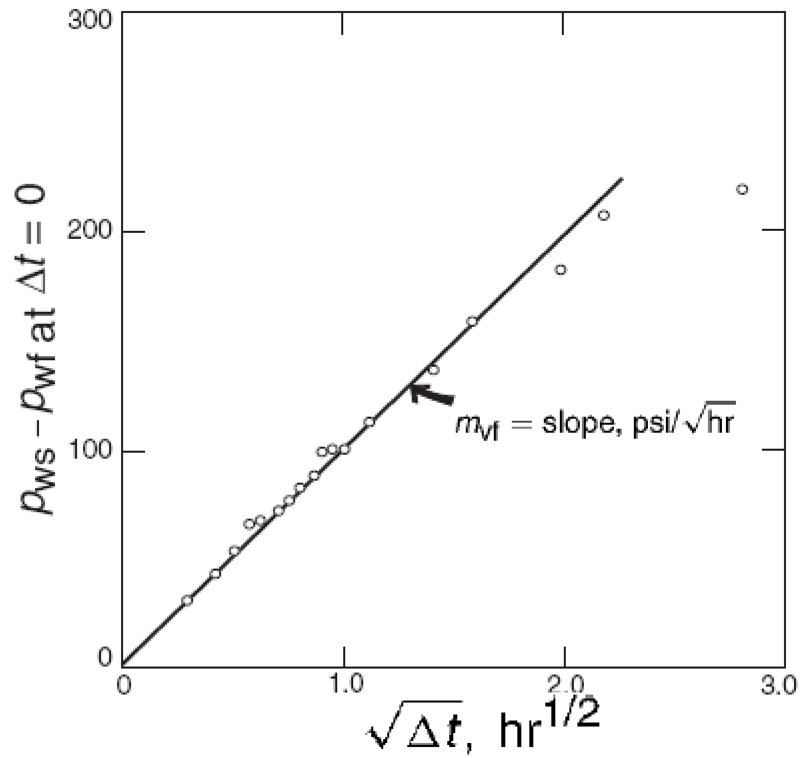
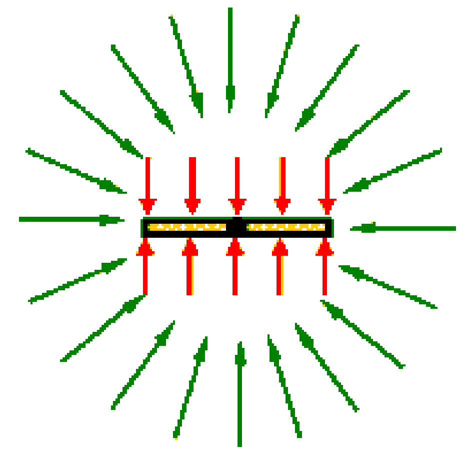


Figure 1.75 *Square-root data plot for buildup test.*

Infinite-Acting Pseudoradial Flow

During this period, the flow behavior is similar to the radial reservoir flow with a negative skin effect caused by the fracture. The traditional semilog and log–log plots of transient pressure data can be used during this period.



$$p_{\mathrm{wf}} = p_{\mathrm{i}} - \frac{162.6 Q_{\mathrm{o}} B_{\mathrm{o}} \mu}{kh} \times \left[\log(t) + \log\left(\frac{k}{\phi \mu c_{\mathrm{t}} r_{\mathrm{w}}^2} \right) - 3.23 + 0.87 s \right]$$

or in a linear form as:

$$p_{\mathrm{i}} - p_{\mathrm{wf}} = \Delta p = a + m \log(t)$$

$$m = \frac{162.6 Q_{\mathrm{o}} B_{\mathrm{o}} \mu_{\mathrm{o}}}{kh} \qquad kh = \frac{162.6 Q_{\mathrm{o}} B_{\mathrm{o}} \mu_{\mathrm{o}}}{|m|} \qquad s = 1.151 \left[\frac{\Delta p_{1\,\mathrm{hr}}}{|m|} - \log\left(\frac{k}{\phi \mu c_{\mathrm{t}} r_{\mathrm{w}}^2} \right) + 3.23 \right]$$

For drawdown $\quad t_{\mathrm{bsf}} \geq 10 t_{\mathrm{elf}}$

For buildup $\quad \Delta t_{\mathrm{bsf}} \geq 10 \Delta t_{\mathrm{elf}}$

Example 1.37 The drawdown test data for an infinite conductivity fractured well is tabulated below:

Additional reservoir parameters are:

$h = 82$ ft,	$\phi = 0.12$
$c_t = 21 \times 10^{-6}$ psi^{-1},	$\mu = 0.65$ cp
$B_o = 1.26$ bbl/STB,	$r_w = 0.28$ ft
$Q = 419$ STB/day,	$p_i = 3770$ psi

Estimate:

- permeability, k;
- fracture half-length, x_f;
- skin factor, s.

t (hr)	p_{wf} (psi)	Δp (psi)	$\sqrt{t}$ ($\mathrm{hr}^{1/2}$)
0.0833	3759.0	11.0	0.289
0.1670	3755.0	15.0	0.409
0.2500	3752.0	18.0	0.500
0.5000	3744.5	25.5	0.707
0.7500	3741.0	29.0	0.866
1.0000	3738.0	32.0	1.000
2.0000	3727.0	43.0	1.414
3.0000	3719.0	51.0	1.732
4.0000	3713.0	57.0	2.000
5.0000	3708.0	62.0	2.236
6.0000	3704.0	66.0	2.449
7.0000	3700.0	70.0	2.646
8.0000	3695.0	75.0	2.828
9.0000	3692.0	78.0	3.000
10.0000	3690.0	80.0	3.162
12.0000	3684.0	86.0	3.464
24.0000	3662.0	108.0	4.899
48.0000	3635.0	135.0	6.928
96.0000	3608.0	162.0	9.798
240.0000	3570.0	200.0	14.142

Solution

Step 1. Plot:

- Δp vs. t on a log–log scale, as shown in Figure 1.77;
- Δp vs. $\sqrt{t}$ on a Cartesian scale, as shown in Figure 1.78;
- Δp vs. t on a semilog scale, as shown in Figure 1.79.

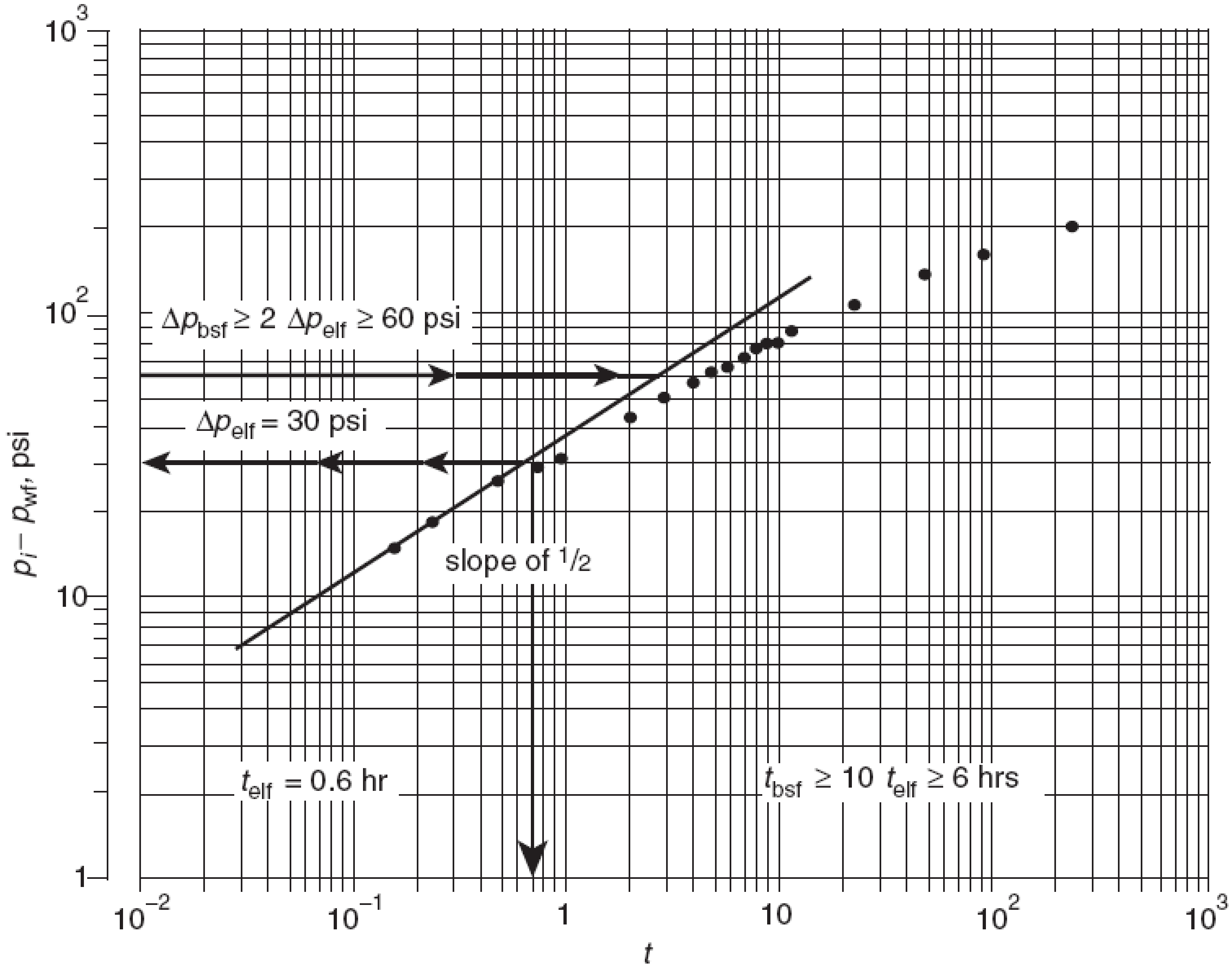


Figure 1.77 *Log–log plot, drawdown test data of Example 1.37 (After Sabet, M. A.* Well Test Analysis *1991, Gulf Publishing Company).*

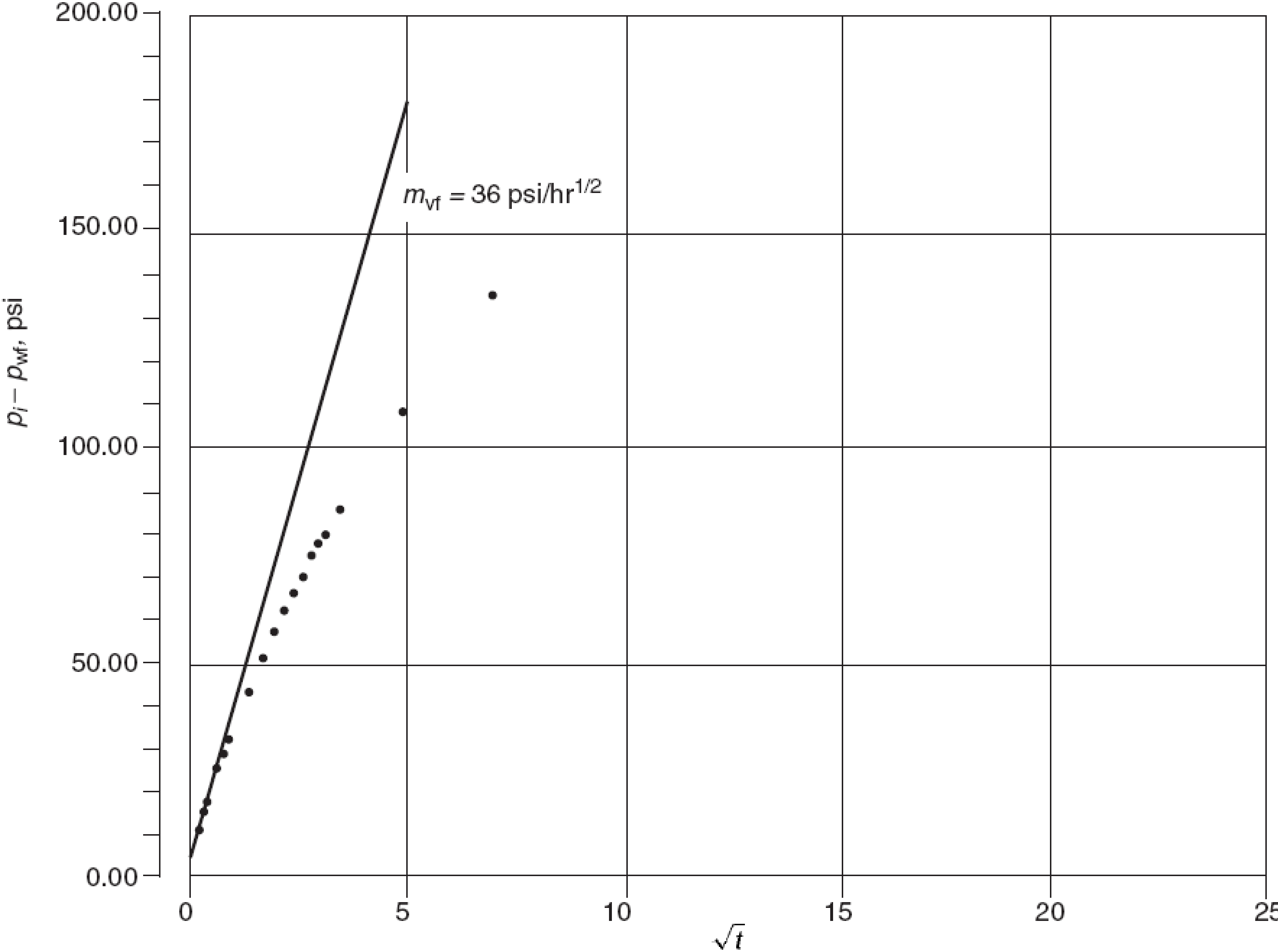


Figure 1.78 *Linear plot, drawdown test data of Example 1.37 (After Sabet, M. A.* Well Test Analysis *1991, Gulf*

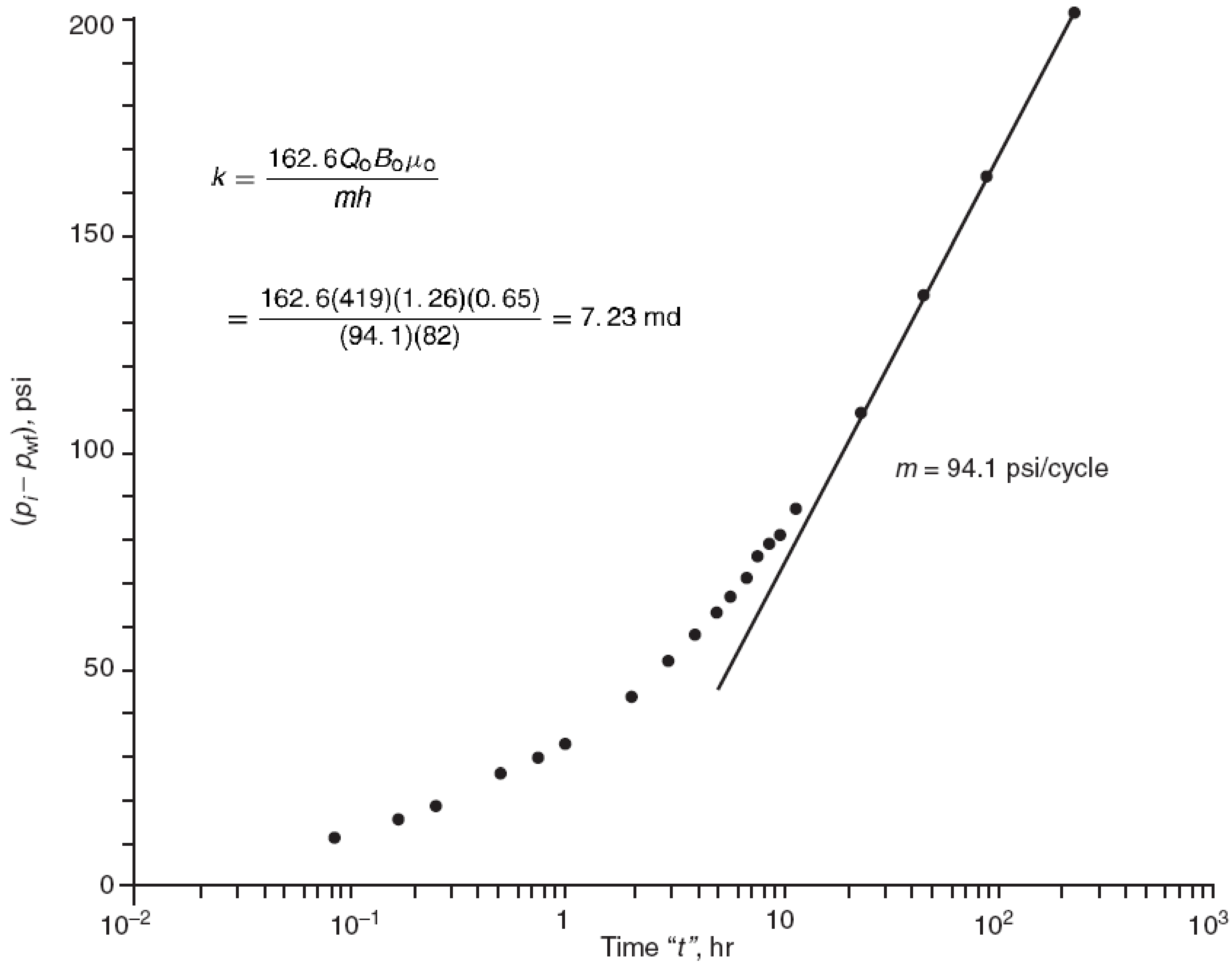


Figure 1.79 *Semilog plot, drawdown test data from Example 1.37.*

Step 2. Draw a straight line through the early points representing $\log(\Delta p)$ vs. $\log(t)$, as shown in Figure 1.77, and determine the slope of the line. Figure 1.77 shows a slope of $\frac{1}{2}$ (not 45° angle) indicating linear flow with no wellbore storage effects. This linear flow lasted for approximately 0.6 hours. That is:

$$t_{\text{elf}} = 0.6 \text{ hours}$$

$$\Delta p_{\text{elf}} = 30 \text{ psi}$$

and therefore the beginning of the infinite-acting pseudoradial flow can be approximated by the "double Δp rule" or "one log cycle rule," i.e., Equations 1.5.40 and 1.5.41, to give:

$$t_{\text{bsf}} \geq 10 t_{\text{elf}} \geq 6 \text{ hours}$$

$$\Delta p_{\text{bsf}} \geq 2 \Delta p_{\text{elf}} \geq 60 \text{ psi}$$

Step 3. From the Cartesian scale plot of Δp vs. $\sqrt{t}$, draw a straight line through the early pressure data points representing the first 0.3 hours of the test (as shown

in Figure 1.79) and determine the slope of the line, to give:

$$m_{\mathrm{vf}} = 36\ \mathrm{psi/hr}^{1/2}$$

Step 4. Determine the slope of the semilog straight line representing the unsteady-state radial flow in Figure 1.79, to give:

$$m = 94.1\ \mathrm{psi/cycle}$$

Step 5. Calculate the permeability k from the slope:

$$k = \frac{162.6 Q_o B_o \mu_o}{mh} = \frac{162.6(419)(1.26)(0.65)}{(94.1)(82)}$$

$$= 7.23\ \mathrm{md}$$

Step 6. Estimate the length of the fracture half-length from Equation 1.5.37, to give:

$$x_f = \left[\frac{4.064QB}{m_{vf}h}\right]\sqrt{\frac{\mu}{k\phi c_t}}$$

$$= \left[\frac{4.064(419)(1.26)}{(36)(82)}\right]\sqrt{\frac{0.65}{(7.23)(0.12)(21 \times 10^{-6})}}$$

$$= 137.3 \text{ ft}$$

Step 7. From the semilog straight line of Figure 1.78, determine Δp at $t = 10$ hours, to give:

$$\Delta p_{\text{at } \Delta t=10} = 71.7 \text{ psi}$$

Step 8. Calculate $\Delta p_{1\,\text{hr}}$ by applying Equation 1.5.39:

$$\Delta p_{1\text{ hr}} = \Delta p_{\text{at } \Delta t=10} - m = 71.7 - 94.1 = -22.4 \text{ psi}$$

Step 9. Solve for the "total" skin factor s, to give

$$s = 1.151\left[\frac{\Delta p_{1\text{ hr}}}{|m|} - \log\left(\frac{k}{\phi\mu c_t r_w^2}\right) + 3.23\right]$$

$$= 1.151\left[\frac{-22.4}{94.1} - \log\left(\frac{7.23}{0.12(0.65)(21 \times 10^{-6})(0.28)^2}\right) + 3.23\right]$$

$$= -5.5$$

with an apparent wellbore ratio of:

$$r_w^{\backslash} = r_w e^{-s} = 0.28e^{5.5} = 68.5\,\mathrm{ft}$$

Notice that the "total" skin factor is a composite of effects that include:

$$s = s_d + s_f + s_t + s_p + s_{sw} + s_r$$

where:

s_d = skin due to formation and fracture damage
s_f = skin due to the fracture, large negative value $s_f \ll 0$
s_t = skin due to turbulence flow
s_p = skin due to perforations
s_w = skin due to slanted well
s_r = skin due to restricted flow

Pressure Response in a Hydraulic Fractured Well

•In general, a fracture could be classified as an infinite conductivity fracture when the dimensionless fracture conductivity is greater than 300, i.e., F_{CD} >300.

$$F_{CD} = \frac{k_f}{k}\frac{w_f}{x_f} = \frac{F_C}{k x_f}$$

Specialized graphs for analysis of the start and end of each flow period:

p vs. (time)$^{0.25}$ for bilinear flow

p vs. (time)$^{0.5}$ for linear flow

p vs. (time)$^{0.5}$ for linear flow

p vs. log(time) for infinite acting pseudo-radial flow

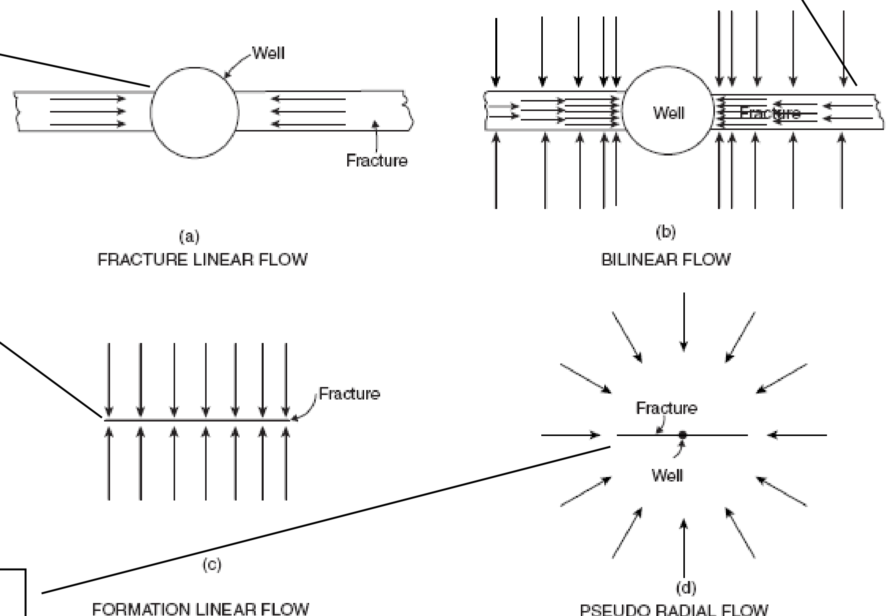
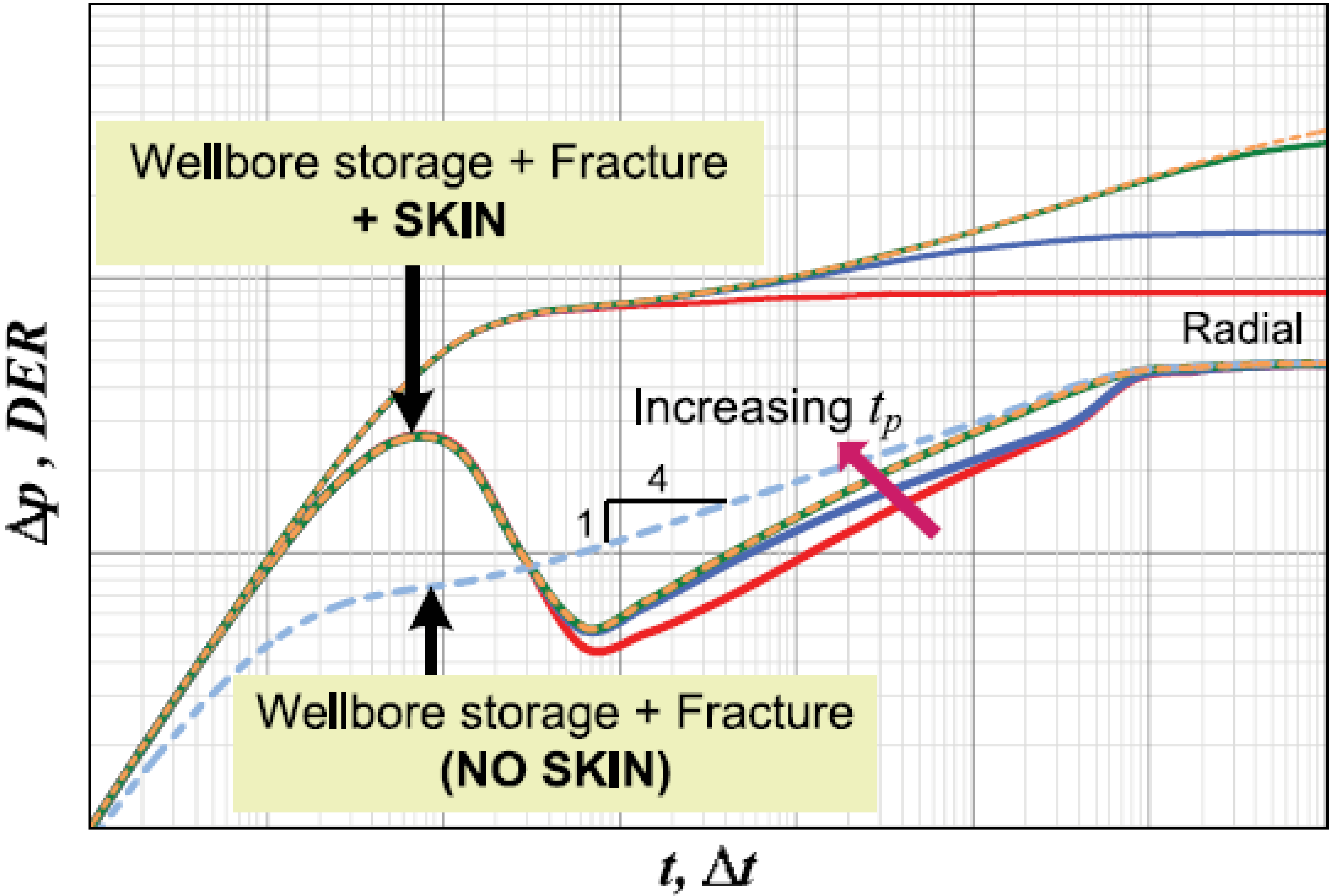
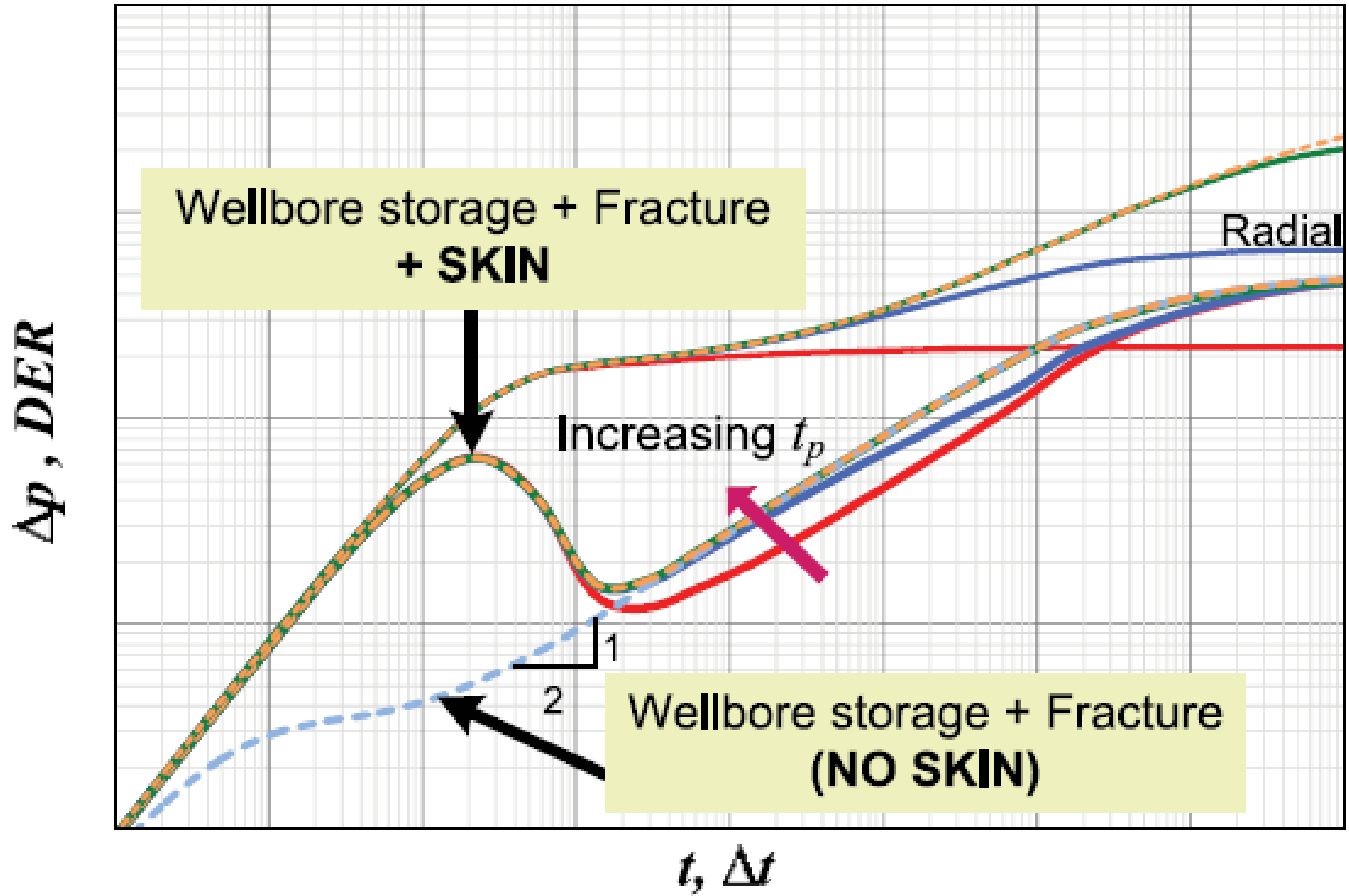


Figure 1.71 *Flow periods for a vertically fractured well (After Cinco and Samaniego, JPT, 1981).*

Finite Conductivity Fracture



Infinite Conductivity Fracture



Hydraulic Fractured Well

- **Hydraulic Fracture (Vertical Well):**
  - Bilinear flow → Finite conductivity fracture
  - Linear flow → Infinite conductivity fracture
  - Wellbore storage hump is evident when fracture has a skin (choke skin or fracture-face skin). Easily misinterpreted as radial flow with complex reservoir geometry
  - Sometimes difficult to differentiate between infinite and finite conductivity when skin is present