Al-Ayen University
College of Petroleum Engineering

Reservoir Engineering II

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Lecture 16: Transient Well Testing (Part 2)

Refs.: Reservoir Engineering Handbook by Tarek Ahmed
Oil Well Testing Handbook by Amanat U. Chaudhry

Outline

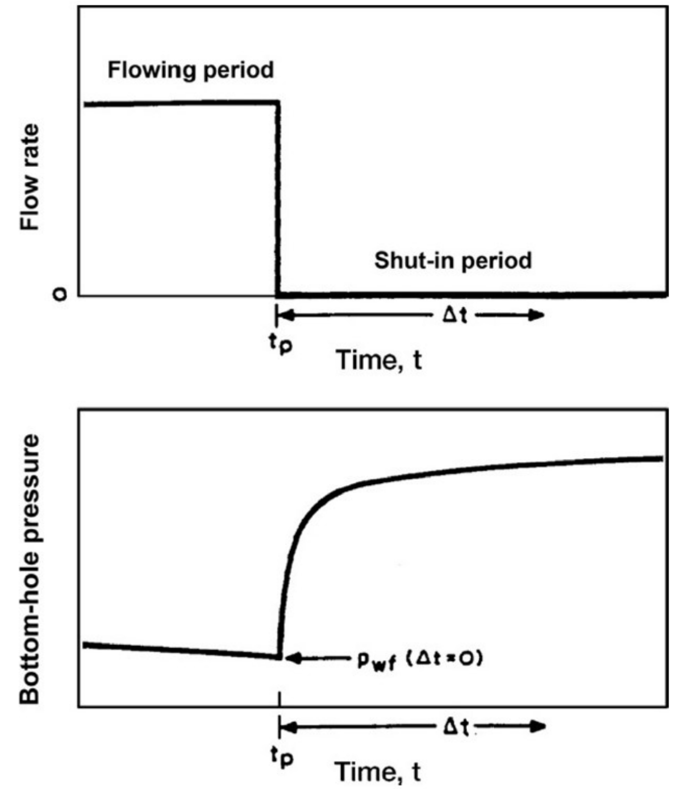
- Pressure Buildup Test
  - Example
- Drill-Stem Test (DST)
  - DST Equipment
  - DST Pressure Behavior
  - Recommended Flow and Shut-in Time for DST
- Summary

Pressure Buildup Test

- Pressure buildup analysis describes the build up in wellbore pressure with time after a well has been shut in. The analysis techniques require that the well produce at a constant rate before shut-in.
- Principal objectives of this analysis is to determine:
  - ➢ The static reservoir pressure
  - ➢ Effective reservoir permeability
  - ➢ Extent of permeability damage around the wellbore
- In pressure buildup and drawdown analyses, the following assumptions, are usually made:
  - ➢ Reservoir: Homogeneous, Isotropic, Horizontal of uniform thickness
  - ➢ Fluid: Single phase, Slightly compressible Constant μ_o and B_o
  - ➢ Flow: Laminar flow, No gravity effects

$$t_p = \frac{24 N_p}{Q_o}$$

N_p = well cumulative oil produced before shut-in, STB
Q_o = stabilized well flow rate before shut-in, STB/day
t_p = total production time, hrs



Idealized pressure buildup test

- Applying the superposition principle to a shut-in well, the total pressure change i.e., (pi – pws):

$$p_i - p_{ws} = (\Delta p)_{total} = (\Delta p)_{due\ to\ (Q_{o1}-0)} + (\Delta p)_{due\ to\ (0-Q_{o1})}$$

$$p_{ws} = p_i - \frac{162.6(Q_o - 0)\mu B_o}{kh}\left[\log\frac{k(t_p+\Delta t)}{\phi\mu c_t r_w^2} - 3.23 + 0.875\,s\right] + \frac{162.6(0 - Q_o)\mu B_o}{kh}\left[\log\frac{k(\Delta t)}{\phi\mu c_t r_w^2} - 3.23 + 0.875\,s\right]$$

Expanding this equation and canceling terms,

$$p_{ws} = p_i - \frac{162.6\,Q_o\,\mu\,B}{kh}\left[\log\frac{(t_p+\Delta t)}{\Delta t}\right]$$

Horner equation (1951)

Where:

p_i = initial reservoir pressure, psi
p_{ws} = sand-face pressure during pressure buildup, psi
t_p = flowing time before shut-in, hr
Δt = shut-in time, hr

$$p_{ws} = p_i - \frac{162.6\, Q_o\, \mu\, B}{kh}\left[\log \frac{(t_p + \Delta t)}{\Delta t}\right]$$

Horner equation (1951)

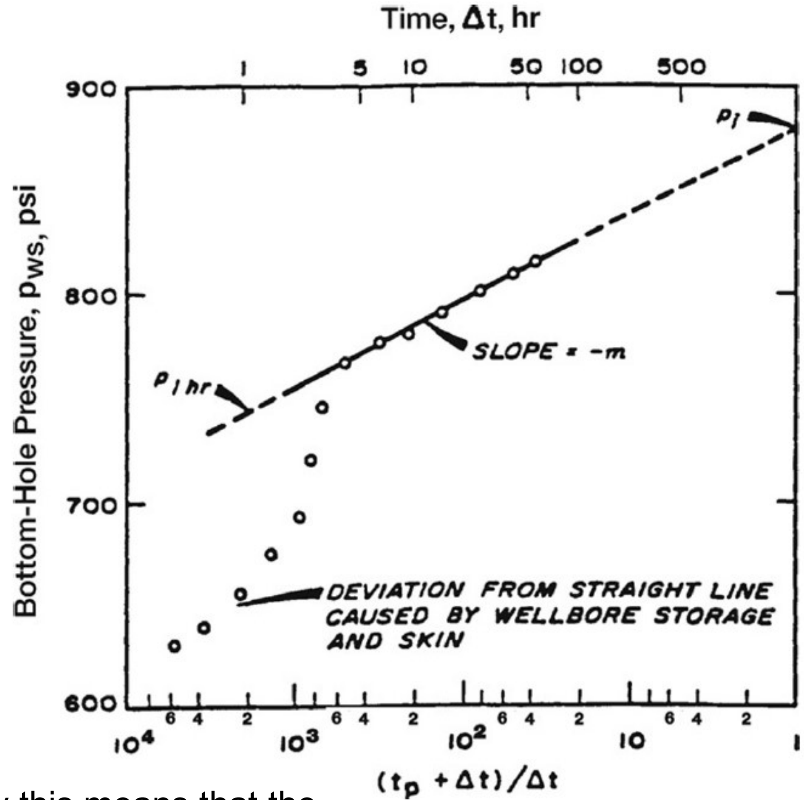
Horner Equation suggests that a plot of pws versus (tp + Δt)/Δt would produce a straight-line relationship with intercept pi and slope of –m, where:

$$m = \frac{162.6\, Q_o\, B_o\, \mu_o}{kh}$$

$$k = \frac{162.6\, Q_o\, B_o\, \mu_o}{mh}$$

$$s = 1.151\left[\frac{p_{1\ hr} - p_{wf}(\Delta t = 0)}{m} - \log \frac{k}{\phi\, \mu\, c_t\, r_w^2} + 3.23\right]$$

$p_{wf}(\Delta t = 0)$ = observed flowing bottom-hole pressure immediately before shut-in
m = slope of the Horner plot, psi/cycle
k = permeability, md
$\Delta p_{skin} = 0.87\, m\, s$
The value of $p_{1\ hr}$ must be taken from the Horner straight line.



- From Horner Equation, pws = pi when the time ratio is unity. Graphically this means that the initial reservoir pressure, pi, can be obtained by extrapolating the Horner plot straight line to (tp + Δt)/Δt = 1.

Example

The Table below shows pressure buildup data from an oil well with an estimated drainage radius of 2,640 ft. Before shut-in, the well had produced at a stabilized rate of 4,900 STB/day for 310 hours. Known reservoir data are:

$$
\begin{aligned}
r_e &= 2{,}640 \text{ ft} \\
\text{depth} &= 10{,}476 \text{ ft} \\
r_w &= 0.354 \text{ ft} \\
c_t &= 22.6 \times 10^{-6} \text{ psi}^{-1} \\
Q_o &= 4{,}900 \text{ STB/D} \\
h &= 482 \text{ ft} \\
p_{wf}(\Delta t = 0) &= 2{,}761 \text{ psig} \\
\mu_o &= 0.20 \text{ cp} \\
\phi &= 0.09 \\
B_o &= 1.55 \text{ bbl/STB} \\
\text{casing ID} &= 0.523 \text{ ft} \\
t_p &= 310 \text{ hours}
\end{aligned}
$$

Calculate:

- Average permeability k
- Skin factor
- Pressure drop due to skin

Earlougher's Pressure Buildup Data
(Permission to publish by the SPE, copyright SPE, 1977)

Δt (hours)	$t_p + \Delta t$ (hours)	$\frac{(t_p + \Delta t)}{\Delta t}$	p_{ws} (psig)
0.0	—	—	2,761
0.10	310.10	3,101	3,057
0.21	310.21	1,477	3,153
0.31	310.31	1,001	3,234
0.52	310.52	597	3,249
0.63	310.63	493	3,256
0.73	310.73	426	3,260
0.84	310.84	370	3,263
0.94	310.94	331	3,266
1.05	311.05	296	3,267
1.15	311.15	271	3,268
1.36	311.36	229	3,271
1.68	311.68	186	3,274
1.99	311.99	157	3,276
2.51	312.51	125	3,280
3.04	313.04	103	3,283
3.46	313.46	90.6	3,286
4.08	314.08	77.0	3,289
5.03	315.03	62.6	3,293
5.97	315.97	52.9	3,297
6.07	316.07	52.1	3,297
7.01	317.01	45.2	3,300
8.06	318.06	39.5	3,303
9.00	319.00	35.4	3,305
10.05	320.05	31.8	3,306
13.09	323.09	24.7	3,310
16.02	326.02	20.4	3,313
20.00	330.00	16.5	3,317
26.07	336.07	12.9	3,320
31.03	341.03	11.0	3,322
34.98	344.98	9.9	3,323
37.54	347.54	9.3	3,323

Solution

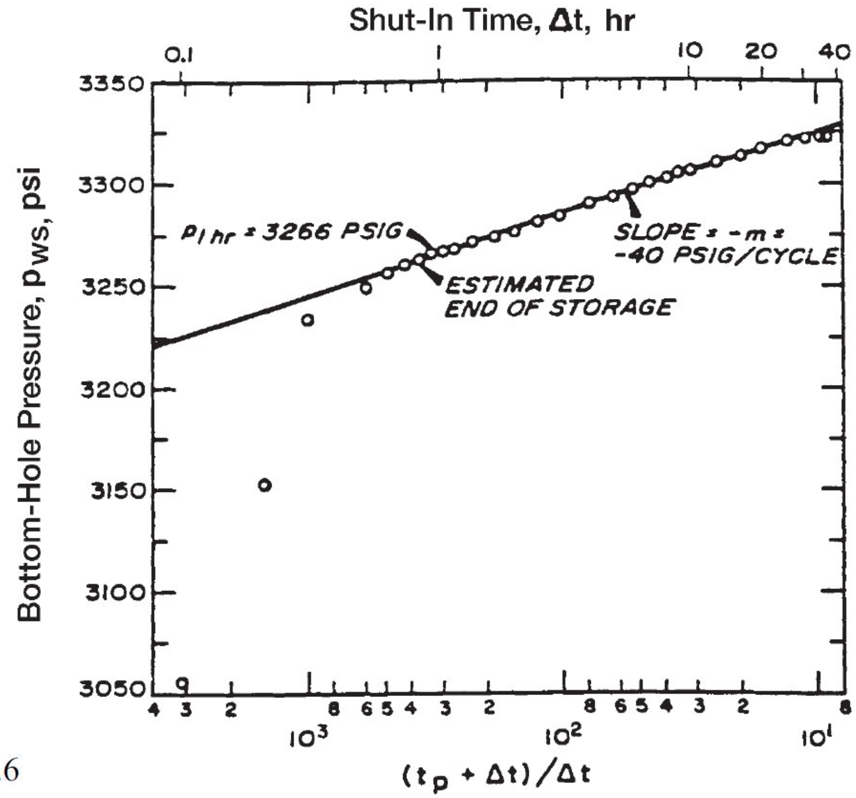
- Plot pws versus (tp + Δt)/Δt on a semilog scale as shown in the Figure.
- Identify the correct straight-line portion of the curve and determine the slope m to give: m = 40 psi/cycle

$$k = \frac{162.6\, Q_o B_o \mu_o}{mh} = \frac{(162.6)(4,900)(1.55)(0.20)}{(40)(482)} = 12.8 \text{ mD}$$

- Determine pwf after 1 hour from the straight-line portion of the curve to give: p1 hr = 3266 psi

$$s = 1.151 \left[\frac{p_{1\ hr} - p_{wf}(\Delta t = 0)}{m} - \log \frac{k}{\phi \mu c_t r_w^2} + 3.23 \right]$$

$$s = 1.1513 \left[\frac{3,266 - 2,761}{40} - \log \left(\frac{(12.8)}{(0.09)(0.20)(22.6 \times 10^{-6})(0.354)^2} \right) + 3.23 \right] = 8.6$$



Δpskin = 0.87ms = 0.87 (40) (8.6) = 299 psi

Drill-Stem Test (DST)

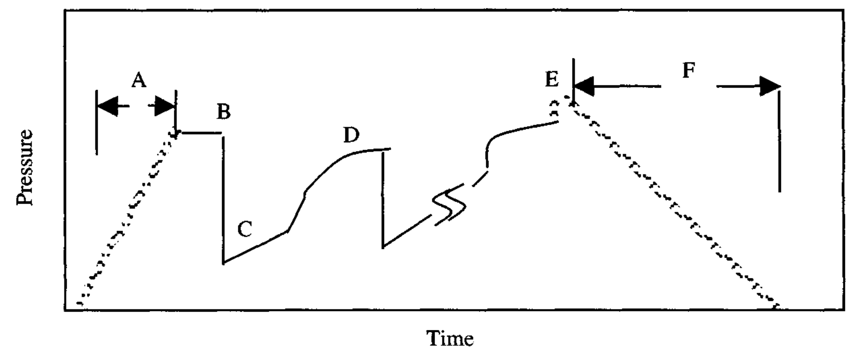
- Drill-stem testing provides a method of temporarily completing a well to determine the productive characteristics of a specific zone.
- Reservoir characteristics that may be estimated from DST analysis include:
  - Average effective permeability.
  - Reservoir pressure: Measured, if shut-in time is sufficient, or calculated, if not.
  - Wellbore damage.
  - Barriers, permeability changes, and fluid contacts: These reservoir anomalies affect the slope of the pressure buildup plot. They usually require substantiating data to differentiate one from the other.
  - Radius of investigation: An estimate of how far away from the wellbore the DST can "see".
  - Depletion: Can be detected if the reservoir is small and the test is properly run.

DST Equipment

- The DST tool is an arrangement of packers and valves placed at the end of the drill pipe.
- The packers help in isolating the zone of interest from drilling mud in the hole and to let it produce into the test chamber, drill collar, and drill pipe.
- The packers also help in reducing wellbore storage effects.

DST Pressure Behavior

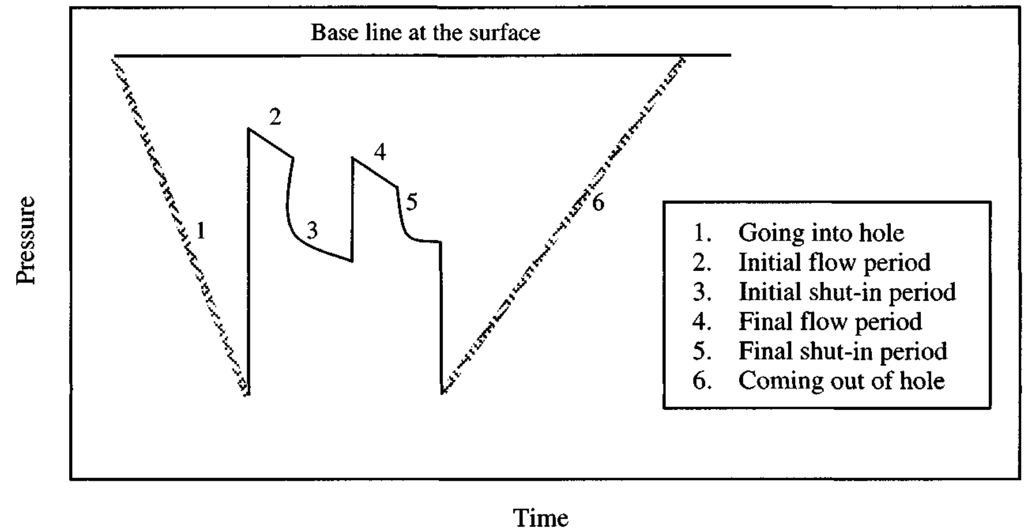
A. Increase in hydrostatic mud pressure as the tool is lowered into the hole.
B. Setting of the packers causes compression of the mud in the annulus in the test interval, and a corresponding increase in pressure is noted.
C. When the tool is opened and inflow from the formation occurs, the pressure behavior is as shown in this section.
D. After the test tool is closed, a period of pressure buildup results.
E. Finally, the test is ended, and the packers are pulled loose, causing a return to hydrostatic mud pressure.
F. Tool is pulled. Fluid recovery from the test may be determined from the contents of the drill pipe or from the amount recovered at the surface if a flowing DST is obtained.



DST pressure record

Recommended Flow and Shut-in Time for DST

- The first flow is very short and is designed (usually 5-15min) to remove any excess pressure, which may have resulted from setting the packers.
- The first buildup is rather long (usually 30-60 min) since reliable value for the initial reservoir pressure is desired.
- The second flow is somewhat longer and is designed (usually 60 min) to evaluate the formation for some distance from the well.
- The second shut-in is usually 30 min to several hours to calculate the transmissibility and other characteristics of the reservoir.
- The Figure shows the DST pressure chart for a two-cycle test. The first cycle in Figure includes the initial flow and buildup periods, while the second cycle includes the second flow and final buildup periods.



DST pressure chart for a two-cycle test

Summary

- Pressure buildup analysis describes the build up in wellbore pressure with time after a well has been shut in.

- Principal objectives of this analysis is to determine: The static reservoir pressure, Effective reservoir permeability and Extent of permeability damage around the wellbore

- Drill-stem test (DST) provides a method of temporarily completing a well to determine the productive characteristics of a specific zone.

- The DST tool is an arrangement of packers and valves placed at the end of the drill pipe.

THANK YOU