Al-Ayen University
College of Petroleum Engineering

Reservoir Engineering II

Lecturer: Dr. Mohammed Idrees Al-Mossawy

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Lecture 15: Principle of Superposition (Part 2) & Transient Well Testing (Part 1)

Refs.: Reservoir Engineering Handbook by Tarek Ahmed

Outline

- Principle of Superposition
  - Effects of the boundary
  - Example
- Transient Well Testing
  - Drawdown Test
  - Example
- Summary

Principle of Superposition

- Mathematically the *superposition theorem* states that *any sum of individual solutions to the diffusivity equation is also a solution to that equation*.
- This concept can be applied to account for the following effects on the transient flow solution:
  - *Effects of multiple wells*
  - *Effects of rate change*
  - *Effects of the boundary*
  - *Effects of pressure change*

Effects of the Reservoir Boundary

- Consider Figure 1, which shows a well that is located a distance r from the non-flow boundary, e.g., sealing fault.
- The no-flow boundary can be represented by the following pressure gradient expression:

$$\left(\frac{\partial p}{\partial r}\right)_{\text{Boundary}} = 0$$

- The total pressure drop at the actual well will be:

$$(\Delta p)_{\text{total}} = (\Delta p)_{\text{actual well}} + (\Delta p)_{\text{due to image well}}$$

$$(\Delta p)_{\text{total}} = \frac{162.6 Q_o B_o \mu_o}{kh}\left[\log\left(\frac{kt}{\phi \mu_o c_t r_w^2}\right) - 3.23 + 0.87s\right] - \left(\frac{70.6 Q_o B_o \mu_o}{kh}\right) E_i\left(-\frac{948 \phi \mu_o c_t (2r)^2}{kt}\right)$$

- Notice that this equation assumes the reservoir is infinite except for the indicated boundary.

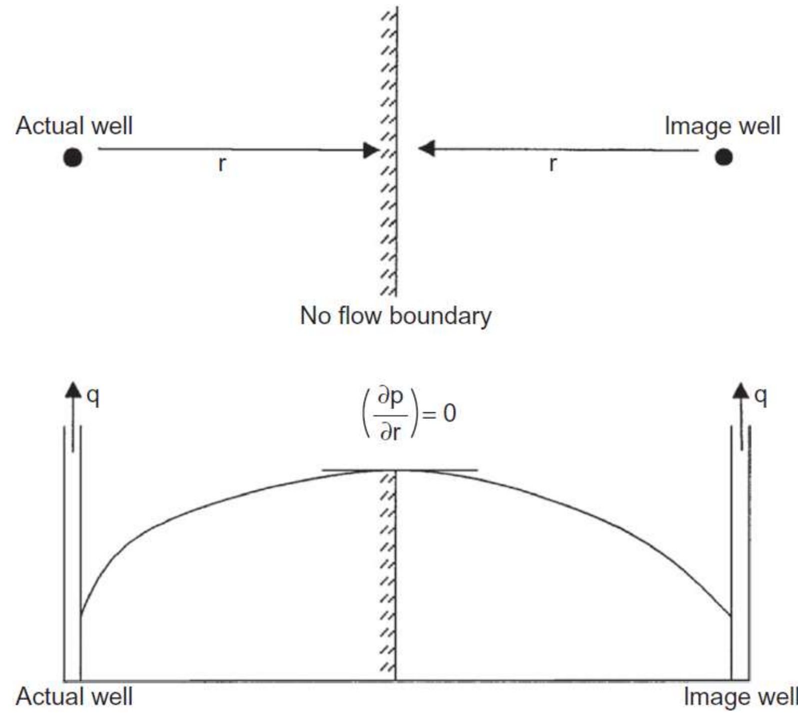


Figure 1: Method of images in solving boundary problems.

- The concept of image wells can be extended to generate the pressure behavior of a well located within a variety of boundary configurations.

Example

Figure 2 shows a well located between two sealing faults at 200 and 100 feet from the two faults. The well is producing under a transient flow condition at a constant flow rate of 200 STB/day.

Given

$$p_i = 5000 \text{ psi} \qquad k = 60 \text{ mD}$$
$$B_o = 1.1 \text{ bbl/STB} \qquad \phi = 17\%$$
$$\mu_o = 2.0 \text{ cp} \qquad h = 25 \text{ ft}$$
$$r_w = 0.3 \text{ ft} \qquad s = 0$$
$$c_t = 25 \times 10^{-6} \text{psi}^{-1}$$

Calculate the sand face pressure after 10 hours.

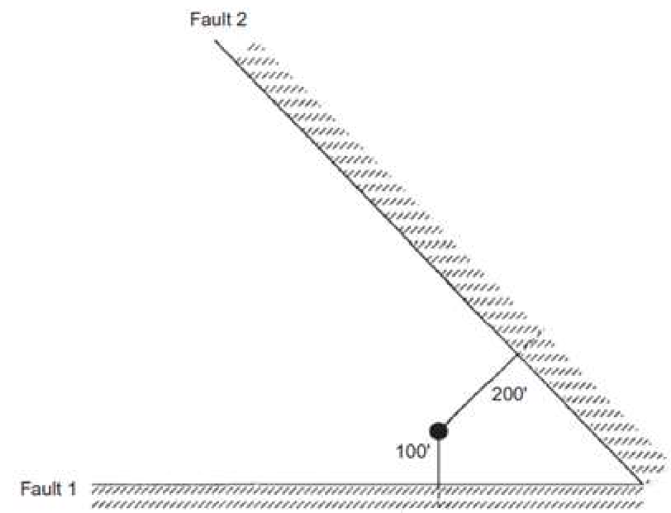


Figure 2: Well layout for Example

Solution

Pwf = Pi – (ΔP) total

$$(\Delta p)_{total} = (\Delta p)_{actual\ well} + (\Delta p)_{due\ to\ image\ well 1} + (\Delta p)_{due\ to\ image\ well 2}$$

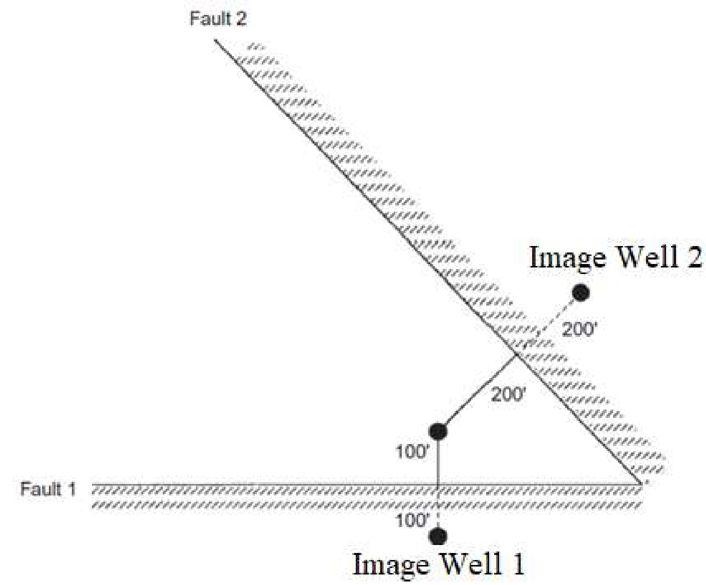
$$(\Delta p)_{actual\ well} = \frac{162.6 Q_{o1} B_o \mu_o}{kh}\left[\log\left(\frac{kt}{\phi \mu c_t r_w^2}\right) - 3.23 + 0.87s\right] = 270.17 \text{ psi}$$

$$(\Delta p)_{image\ well 1} = \left(\frac{70.6 Q_o B_o \mu_o}{kh}\right) E_i\left(-\frac{948 \phi \mu_o c_t (2r)^2}{kt}\right) = 10.64 \text{ psi}$$

$$(\Delta p)_{image\ well 2} = \left(\frac{70.6 Q_o B_o \mu_o}{kh}\right) E_i\left(-\frac{948 \phi \mu_o c_t (2r)^2}{kt}\right) = 1.0 \text{ psi}$$

$$(\Delta p)_{total} = 270.17 + 10.64 + 1.0 = 281.8 \text{ psi}$$

$$p_{wf} = 5000 - 281.8 = 4718.2 \text{ psi}$$



Transient Well Testing

A transient test is conducted by creating a pressure disturbance in the reservoir and recording the pressure response at the wellbore, i.e., bottom-hole pressure, as a function of time.

Some of the pressure transient tests are:

- Pressure drawdown test
- Pressure buildup test
- Multirate test
- Interference test
- Drill stem test (DST)
- Injectivity test
- Fall off test

Information available from a well test includes:

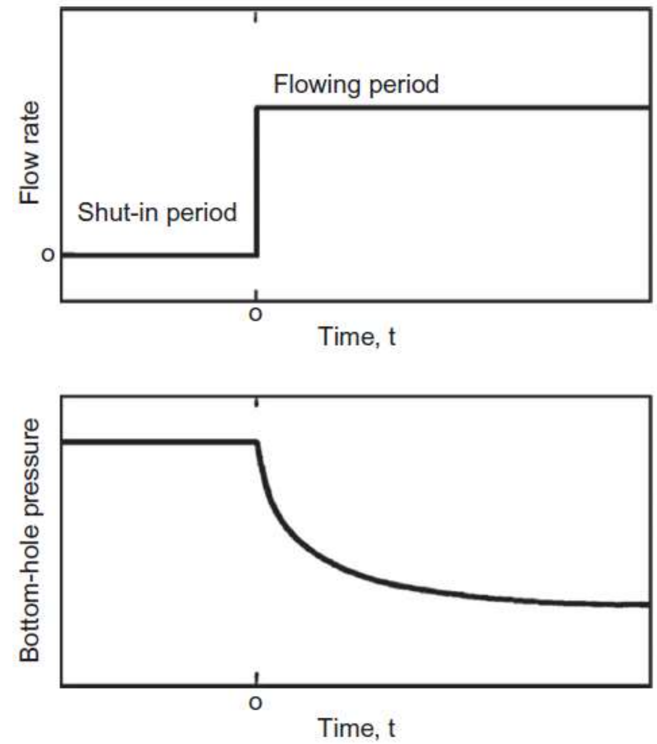
- Effective permeability
- Formation damage or stimulation
- Flow barriers and fluid contacts
- Volumetric average reservoir pressure
- Drainage pore volume
- Detection, length, capacity of fractures
- Communication between wells

Drawdown Test

- A pressure drawdown test is simply a series of bottom-hole pressure measurements made during a period of flow at constant producing rate.

- Usually, the well is shut-in prior to the flow test for a period of time sufficient to allow the pressure to equalize throughout the formation, i.e., to reach static pressure.

- The fundamental objectives of drawdown testing are to obtain the *average permeability* and *skin factor*.



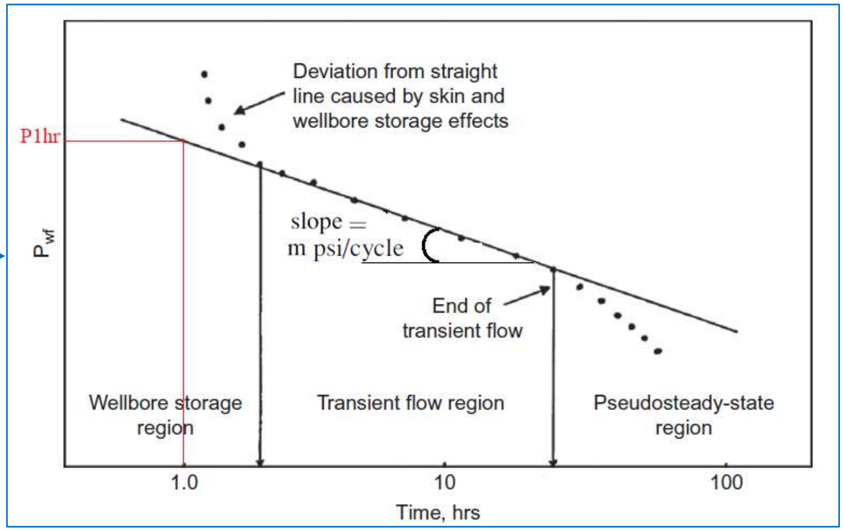
Idealized drawdown test

- During flow at a constant rate of Qo, the pressure behavior of a well in an infinite-acting reservoir is given by Equation:

$$p_{wf} = p_i - \frac{162.6\, Q_o\, B_o\, \mu}{kh}\left[\log\left(\frac{kt}{\phi\, \mu\, c_t\, r_w^2}\right) - 3.23 + 0.87s\right]$$

$$p_{wf} = p_i - \frac{162.6\, Q_o\, B_o\, \mu}{kh}\left[\log(t) + \log\left(\frac{k}{\phi\, \mu\, c_t\, r_w^2}\right) - 3.23 + 0.87s\right]$$

$$p_{wf} = a + m\log(t)$$ → Straight line equation →



where $$a = p_i - \frac{162.6\, Q_o\, B_o\, \mu}{kh} \times \left[\log\left(\frac{k}{\phi\, \mu\, c_t\, r_w^2}\right) - 3.23 + 0.87s\right]$$

The slope m is given by: $$m = \frac{-162.6 Q_o B_o \mu_o}{kh} \text{ psi/cycle}$$

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

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

Example

Estimate oil permeability and skin factor from the drawdown data of Figure 3.

The following reservoir data are available:

$h = 130\ \text{ft}$ $\qquad \phi = 20\ \text{percent}$

$r_w = 0.25\ \text{ft}$ $\qquad p_i = 1,154\ \text{psi}$

$Q_o = 348\ \text{STB/D}$ $\qquad B_o = 1.14\ \text{bbl/STB}$

$\mu_o = 3.93\ \text{cp}$ $\qquad c_t = 8.74 \times 10^{-6}\ \text{psi}^{-1}$

Solution

From Figure 3, calculate $p_{1\ hr}$: $p_{1\ hr} = 954$ psi

Determine the slope of the transient flow line: $m = -22$ psi/cycle

$$k = \frac{-162.6 Q_o B_o \mu_o}{mh} \qquad k = \frac{-(162.6)(348)(1.14)(3.93)}{(-22)(130)} = 88.64\ \text{mD}$$

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

$$s = 1.151\left\{\left(\frac{954 - 1,154}{-22}\right) - \log\left[\frac{88.64}{(0.2)(3.93)(8.74\times10^{-6})(0.25)^2}\right] + 3.23\right\} = 4.61$$

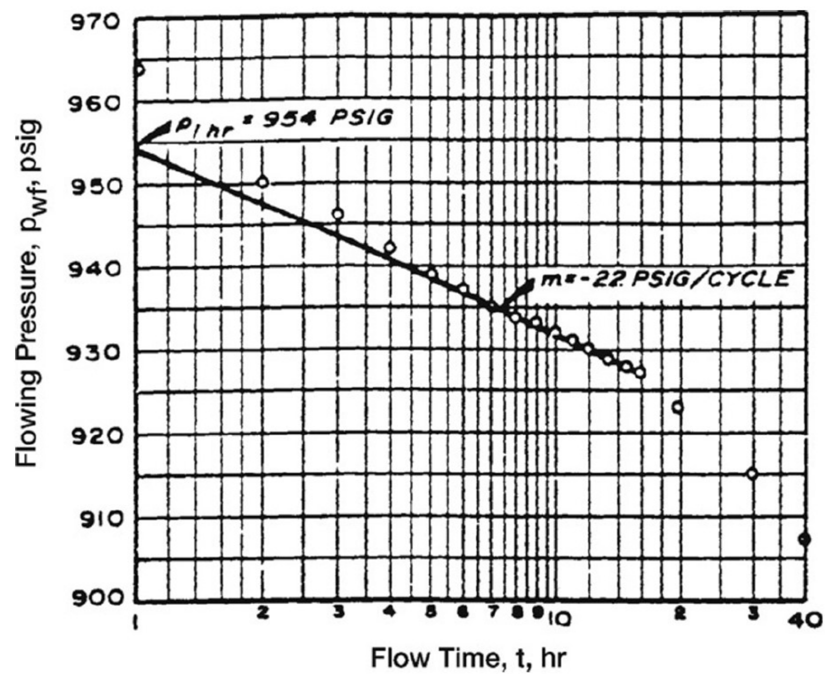


Figure 3: Earlougher's semilog data plot for the drawdown test

Summary

- The no-flow boundary can be represented by the method of image well.
- A transient test is conducted by creating a pressure disturbance in the reservoir and recording the pressure response at the wellbore, i.e., bottom-hole pressure, as a function of time.
- A pressure drawdown test is simply a series of bottom-hole pressure measurements made during a period of flow at constant producing rate.
- The fundamental objectives of drawdown testing are to obtain the *average permeability* and *skin factor*.

THANK YOU