CHAPTER III

THEORIES AND CONCEPTS

3.1 Pressure Transient Analysis for Well Test and Wireline Formation Test

In well test analysis, pressure transient analysis (PTA) is used as a tool to evaluate reservoir parameters. The pressure response from the reservoir is monitored while the production or injection process takes place. The pressure transient analysis is an inverse problem by setting the flow rate history as input and the pressure response as output as shown in Figure 3.1. Then, we analyze the model response by using a mathematical model. Therefore, the characteristic of pressure response can infer the reservoir parameters.

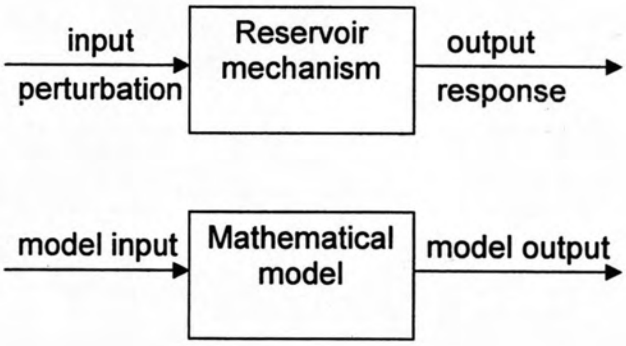

Figure 3.1 : Inverse problem

3.2 Types of Tests

There are several types of tests such as drawdown test, build up test, injection test, falloff test, interference test, and drill stem test (DST). The use of tests depending on the test objectives or practical limitations. In this work, the test is focused on drawdown test and build up test. The descriptions of drawdown and build up test are presented below.

3.2.1 Drawdown Test

In a drawdown test, the well is flowed at a constant rate, and the well flowing pressure is measured downhole. Since the well is put on production, the measured pressure decreases (draws down) as shown is Figure 3.2. In general, it is difficult to control the flow rate to be constant and if the well is recently drilled, it may not be able to stabilize at initial condition. However, drawdown testing is a good method to test reservoir limit because over a long period of time, fluctuations in flow rate become less significant.

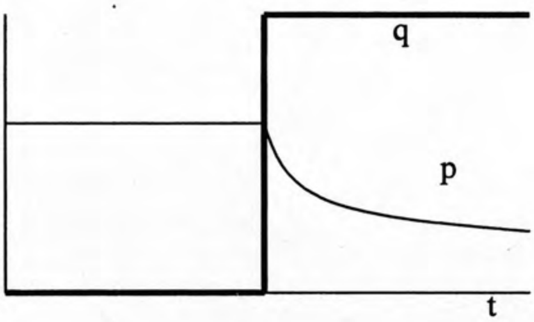

Figure 3.2 : Drawdown test.

3.2.2 Build up Test

In a build up test, a well is produced with a constant flow rate for a period of time and then the well is shut in. During this period, the downhole pressure is measured as the pressure builds up. The measured pressure increases (builds up) when the well is shut in as shown in Figure 3.3. The practical advantage of build up test is that it is easy to control the flow rate to be constant because the buildup flowrate is zero. However, the buildup test also has disadvantages such as loss of fluid production during the shut-in period.

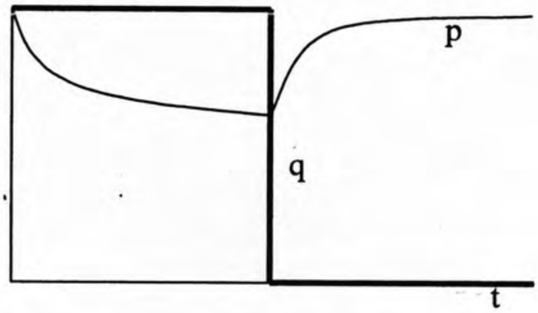

Figure 3.3 : Buildup test.

3.3 Well Test Concept

In order to understand the reservoir characteristic, an analytical reservoir model is developed to match the model response to the measured reservoir response to describe the flow of single-phase slightly compressible fluid in a porous medium. The basic equations of reservoir model are obtained by combining conservation of mass (material balance equation) or conservation of mass fluxes as shown in Figure 3.4. with conservation of momentum (Darcy's Law)

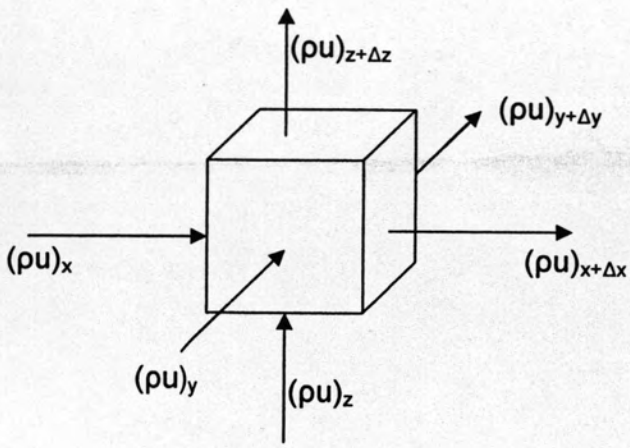

Figure 3.4 : Mass fluxes in porous media

Over the time interval Δt, the conservation of mass equation is

$$\text{Mass In} - \text{Mass Out} = \text{Increase in Storage} \tag{3.1}$$

After substituting expressions for each term in the equation and some derivativation, the governing equation is the diffusion equation

$$\nabla^2 p = \frac{\phi \mu c_t}{k} \frac{\partial p}{\partial t} \tag{3.2}$$

where p = pressure
ϕ = porosity
μ = fluid viscosity
c_t = total compressibility
k = formation permeability
t = time
ρ = fluid density
u = fluid velocity

where s = skin factor (dimensionless pressure)
k = undamaged formation permeability (mD)
h = formation thickness (ft)
q_{sc} = production rate (STB/D)
B = formation volume factor (RB/STB)
μ = viscosity (cp)
Δp_s = pressure drop caused by skin (psi)
k_s = damaged formation permeability (mD)
r_s = radius of invasion (ft)
r_w = wellbore radius (ft)

The skin zone permeability k_s can be higher than that of the undamaged reservoir due to stimulation by hydraulic fracturing or acidizing. From Equation 3.4, if k is less than k_s, the skin factor can be negative. The pressure drop of stimulated well can be lower than that of undamaged well as shown in Figure 3.6.

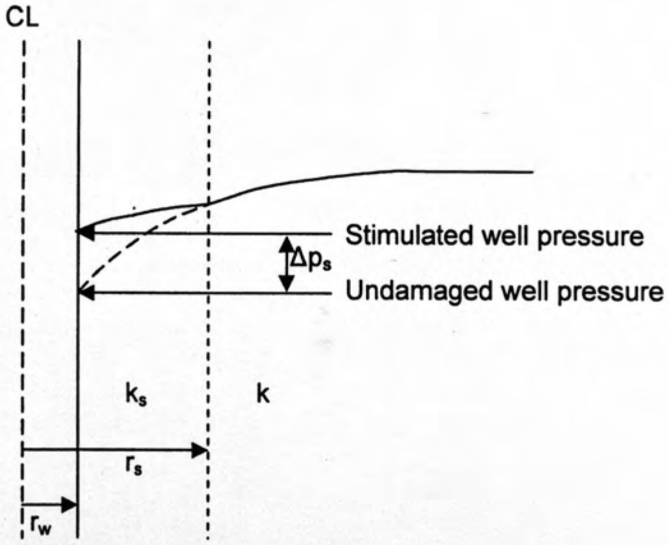

Figure 3.6 : Pressure profile of a stimulated well.

3.5 Wireline Formation Test Concepts

Pressure transient analysis for wireline formation test is based on the same principal as advanced well test analysis technique to obtain reservoir information. In wireline formation test, there are three main possible flow regimes which are linear flow, radial flow or cylindrical flow, and spherical flow. The linear flow is a flow regime characterized by parallel flow lines in a fracture well. The linear flow equation was considered by Cinco and Samaniego (1981). After the period of linear flow is radial flow. In 1951, Horner derived the radial flow equation for buildup period, and after that Moran and Finklea presented the spherical flow equation in 1962. The equations are shown below respectively.

For linear flow, Cinco and Samaniego (1981) developed the pressure drop equation

$$p_D = \left(\pi t_{Dxf}\right)^{1/2} \tag{3.6}$$

The linear flow starts approximately at

$$t_{Dxf} = \frac{100}{\pi FC_D^2} \tag{3.7}$$

and ends at

$$t_{Dxf} = 0.016 \tag{3.8}$$

where FC_D is the fracture conductivity, which is defined as

$$FC_D = k_{fD} w_{fD} \tag{3.9}$$

where the dimensionless fracture permeability k_{fD} and dimensionless fracture w_{fD} width are defined as

$$k_{fD} = \frac{k_f}{k} \tag{3.10}$$

and

$$w_{fD} = \frac{w}{X_f} \tag{3.11}$$

where k_f = the permeability of the fracture, md.
w = fracture width (aperture), ft.
x_f = fracture length, ft.

The dimensionless pressure p_D is defined as

$$p_D = \frac{kh}{141.2 q_{sc} B\mu}(p_i - p_{wf}) \tag{3.12}$$

where k = permeability (md)
h = thickness (feet)
p_i = initial reservoir pressure (psi)
p_{wf} = well flowing pressure (psi)
q = production rate (STB/d)
B = formation volume factor (res vol/std vol)
μ = viscosity (cp)

For radial flow, Horner (1951) derived the equation for buildup period

$$p(t) = p_i - \frac{\mu}{4\pi kh}\frac{V}{t}\left[\ln(t + \Delta t) - \ln \Delta t\right] \tag{3.13}$$

For spherical flow, Moran and Finklea (1962) developed the equation

$$p(t) = p_i - \frac{\mu}{4\pi k}\sqrt{\frac{\alpha}{\pi}}\,\frac{V}{t}\left[\frac{1}{\sqrt{\Delta t}} - \frac{1}{\sqrt{t+\Delta t}}\right] \tag{3.14}$$

where μ = fluid viscosity (poises)
k = formation permeability (cm^2)
α = $\mu c\phi / k$ (sec/cm^2)
c = compressibility (cm^2/dyne)
V = total volume of fluid produced (cm^2)
t = total time the tool is opened (sec)
Δt = time after the tool is closed (sec) (time for buildup)
p_i = initial reservoir pressure (dynes/cm^2)
$p(t)$ = pressure at any time t (dynes/cm^2)
A = cross-sectional area (cm^2)
h = bed thickness of interval tested (cm)

In this study, we use the equation for spherical flow developed by Whittle (2003) as follows :

$$\Delta p = \frac{qB\mu}{2a_1 k_{xyz} r_s}\left[1 - \sqrt{\frac{\phi\mu c_t {r_s}^2}{\pi a_2 k_{xyz}}}\,\frac{1}{\sqrt{\Delta t}} + S_p\right] \tag{3.15}$$

The spherical permeability is

$$k_{xyz} = \sqrt[3]{k_x k_y k_z} = \sqrt[3]{{k_{xy}}^2 k_z} \tag{3.16}$$

And, the horizontal permeability is

$$k_{xy} = \sqrt{k_x k_y} \tag{3.17}$$

where μ = fluid viscosity (cp)
ϕ = porosity (fraction)
k_{xyz} = spherical permeability (mD)
k_{xz} = horizontal permeability (mD)
k_z = vertical permeability (mD)
c_t = total compressibility (psi^{-1})
B = formation volume factor (RB/STB)
Δt = time (hrs)
p_i = initial reservoir pressure (psi)
Δp = pressure drop (psi)
q = flowrate (STB/Day)
r_s = probe radius (ft)
S_p = probe skin factor
a_1 = 0.00708
a_2 = 0.0002637

3.6 Wireline Formation Flow Regimes

In 1983, Bourdet *et al.* first introduced the pressure derivative plot to characterize the flow regimes in a single plot. The derivative plot is a plot of log Δp vs. log Δt and log $td\Delta p/dt$ vs. log Δt. During wireline formation test, the pressure derivative curve can show a number of shapes depending on flow regimes such as spherical flow, hemispherical flow or radial flow. Some of flow regimes are described below.

3.6.1 Spherical Flow

At early time, pressure response is dominated by the tool storage effect. This effect will show a hump in pressure derivative plot. At middle time, the flow regime is spherical flow because the fluid in the formation flows into the probe through a small flow hole as shown in Figure 3.7. This flow regime can be observed by a straight line with a negative half-unit slope in a pressure derivative log-log plot as shown in Figure 3.8. The spherical flow regime is controlled by spherical permeability, k_{xyz} and from this flow regime k_{xyz} can be estimated.

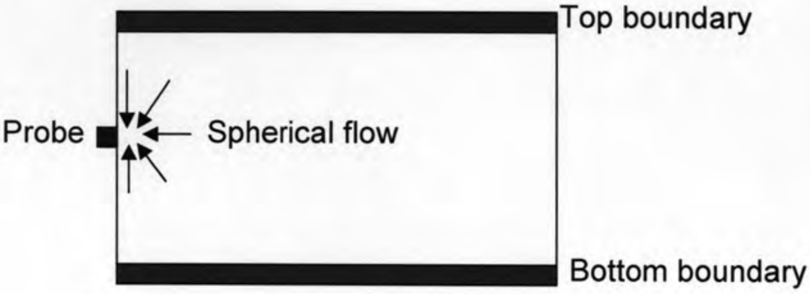

Figure 3.7 : Spherical flow regime.

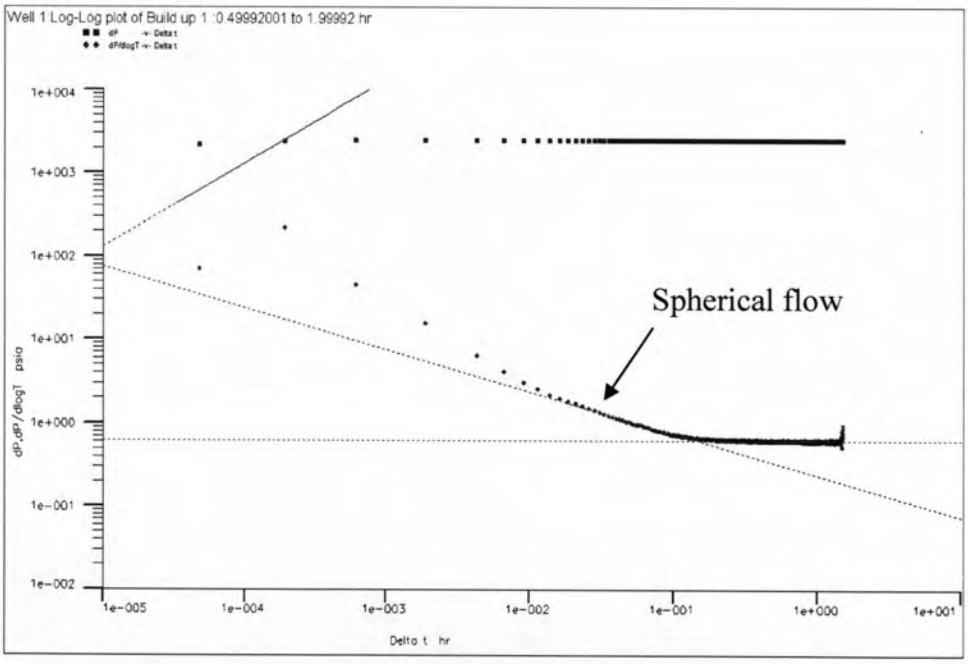

Figure 3.8 : Pressure change and pressure derivative obtained from wireline formation test showing spherical flow.

3.6.2 Radial Flow

At late time, the flow regime changes to radial flow or cylindrical flow. The radial flow regime occurs when the top and bottom boundaries of the reservoir are no-flow boundaries and close enough to influence the pressure transients as shown in Figure 3.9. If the distances between the top boundary and the bottom boundary are known, vertical to horizontal permeability ratio can be estimated.

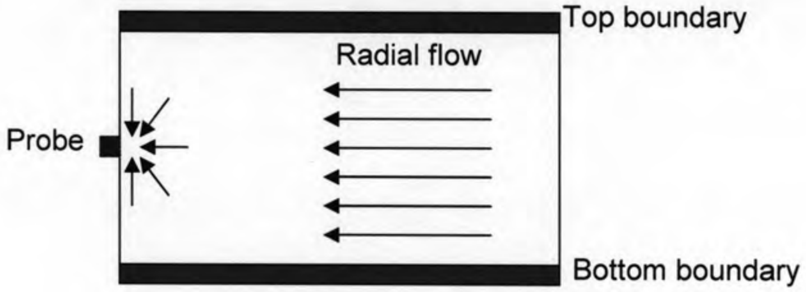

Figure 3.9 : Radial flow regime.

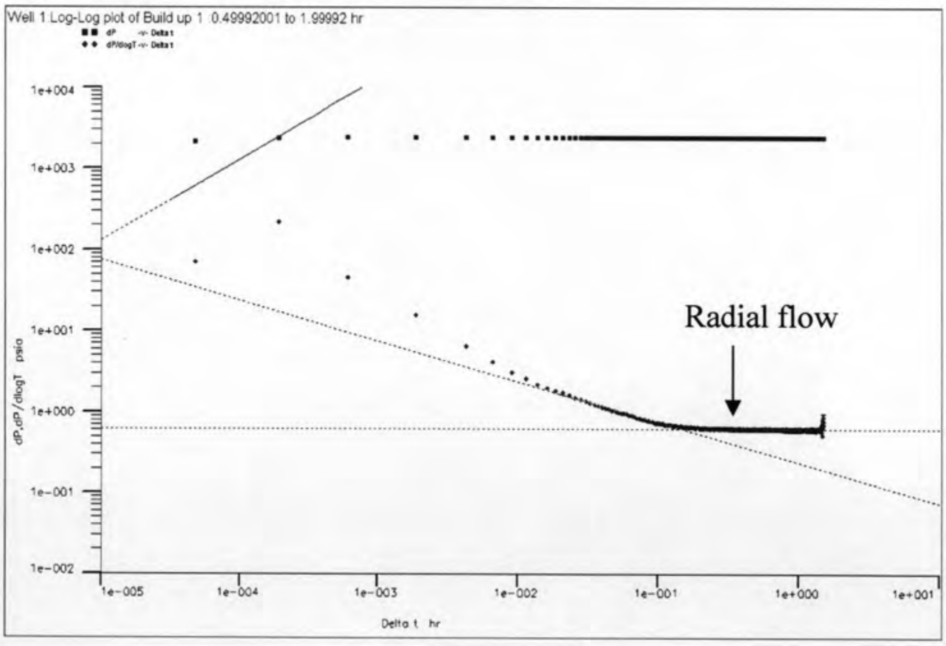

Figure 3.10 : Pressure change and pressure derivative obtained from wireline formation test showing radial or cylindrical flow.

3.6.3 Hemispherical Flow

Hemispherical flow occurs when the probe is set near one of the no flow boundaries no matter top or bottom boundary as sketched in Figure 3.11. This flow regime can be identified by another negative half-unit slope in a pressure derivative log-log plot following a negative half-unit slope of spherical flow regime as shown in Figure 3.12.

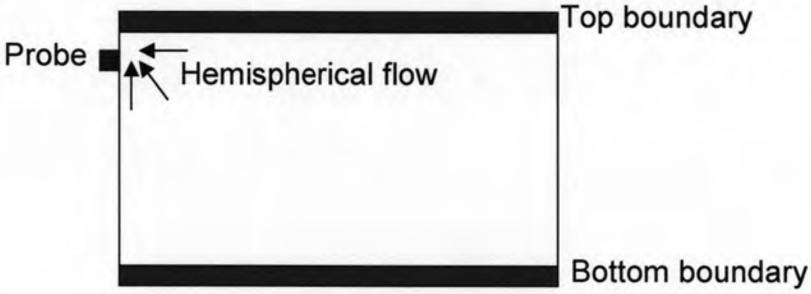

Figure 3.11 : Hemispherical flow regime.

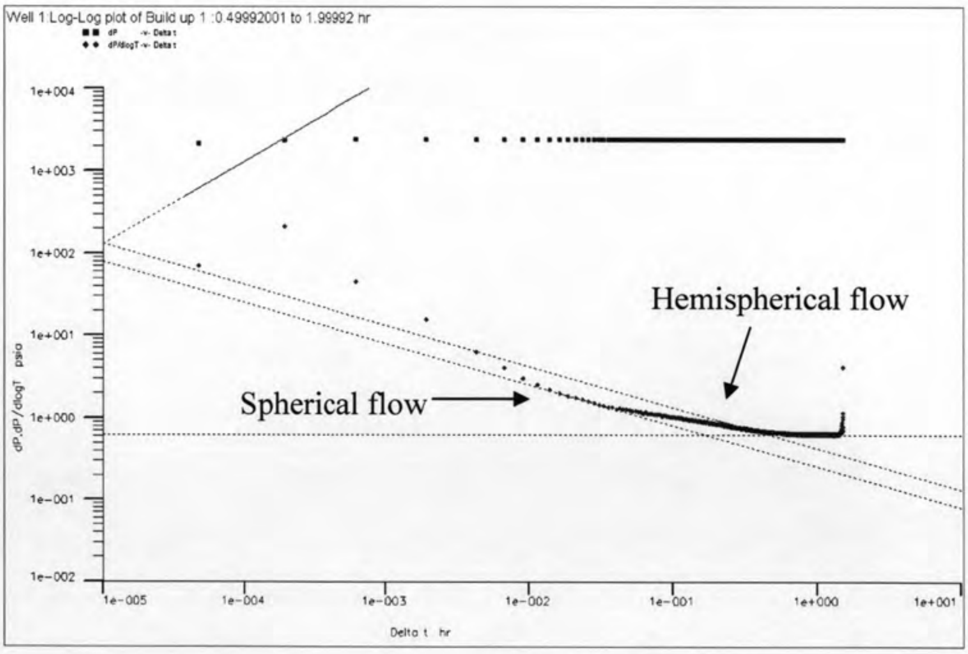

Figure 3.12 : Pressure change and pressure derivative obtained from wireline formation test showing hemispherical flow.