Lecture Notes

PET504E Advanced Well Test Analysis

January 2012

by
Prof. Dr. Mustafa Onur

1 Introduction

The term "Well Testing" [c1]as it is used in Petroleum Industry means the measuring of a formation's (or reservoir's) pressure (and/or rate) response to flow from a well. The term "Well Testing" is generally used with the term "Pressure Transient Analysis", interchangeably. It is an indirect measurement technique as opposed to direct methods such as fluid sampling or coring. Well testing provides dynamic information on the reservoir whereas direct measurements only provide static information, which is not sufficient for predicting the behavior of the reservoir.

[c1] *Murat Çınar*: *Text added.*

Simply, the objective of well testing is to deduce quantitative information about the well/reservoir system under consideration from its response to a given input. Input (or input signal) is used for perturbing one or more wells so that the output (signal) exhibiting the response of the reservoir is obtained at the perturbated well and/or adjacent wells. In practice, the input is equivalent to controlling the well behavior [c2] created by changing the flow rate or the pressure at the well (Mathematically specifying the well behavior is equivalent to specifying a boundary condition). A common example for creating an input signal is [c3]a build up test [c4]where we change the rate to zero by shutting-in the well. Reservoir response, [c5] also called output signal, to a given input is monitored by measuring the pressure change (or rate change) at the [c6] well. This process is illustrated as,

[c2] *Murat Çınar*: ~~and~~

[c3] *Murat Çınar*: *Text added.*

[c4] *Murat Çınar*: ~~in which~~

[c5] *Murat Çınar*: ~~which is~~

[c6] *Murat Çınar*: ~~same~~

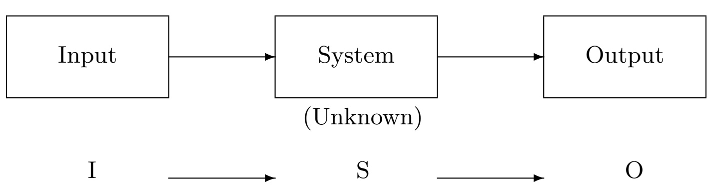

Fig. 1.1. Block diagram ?????

Typical examples for input and output signals as used in petroleum industry are shown in Fig. 1.2.

From reservoir response as monitored by the "output signal", we would like to determine information related to the followings:

- Fluid in place; pore volume, ϕhA.

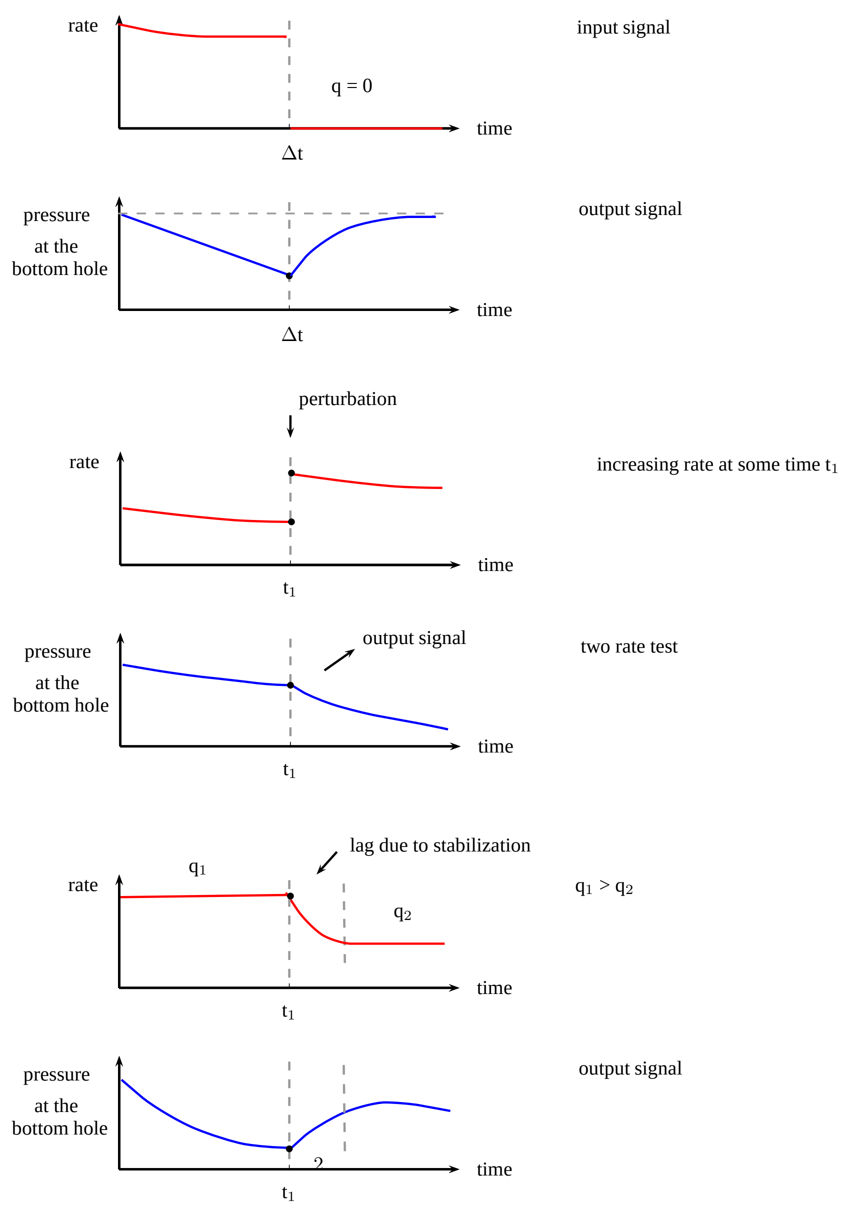

Fig. 1.2. Typical input and output signals - Transient phenomena.

– Ability of reservoir to transfer fluid, kh (or transmissibility, $\frac{kh}{\mu}$).
– Determination of average reservoir [c1]pressure, $\overline{P}$, which is the driving force in the reservoir [c2]
– Prediction of rate versus time data.
– Initial recovery, is the reservoir worth producing.
– Is there any damage around the wellbore impeding the flow? skin factor, s.
– Reservoir description (type of reservoir, flow boundaries (faults)).
– Distance to fluid interface [c3]that is important determining swept zone for secondary and tertiary methods.

Interpretation of well test data consist of basically three steps:

(i) Determination of the one most appropriate reservoir / wellbore (mathematical) model [c4]of the actual system. We also call such a model as the interpretation model. [c5]Here our intention is to find a representative mathematical model that reproduces, as close as possible, the output of the actual system for a given input. This is known as the inverse problem. [c6]We are trying to obtain information about the physical system by using observed measurements. Unfortunately, the solution of inverse problem often yields non-unique results. [c7]By non-unique results, we mean that several different interpretation models [c8]may generate an output signal (response) to a given input [c9]that is similar (or identical) to that of the actual system. The inverse problem can be represented by the following equation.

$$\Sigma = O/I \ \approx S \tag{1.1}$$

where Σ denotes the interpretation model, S denotes the actual system. In inverse problem, as can be seen from Eq.1.1, it may be possible to obtain the same outputs to a given I for different Σ_i's[c10],however, the number of alternative models (solutions) can be reduced as the number and the range of output signal measurements.

(ii) Once the appropriate model is determined, estimate the parameters of the actual system S. [c11]These parameters are kh, s, ϕ, C, λ, w etc. This is known as [c12]parameter estimation[c13][c14] and achieved by adjusting the parameters of the model by different [c15]mathematical methods to obtain an output signal, Ω, that is always qualitatively identical (within some tolerance) to that of [c16]the actual system, O. The computation of Ω is known as the "[c17]forward problem" in mathematics. Contrary to the inverse problem, the solution of the [c18]forward problem is always unique for a given system; that is,

$$I \times \Sigma = \Omega \approx 0 \tag{1.2}$$

The adjusted parameters of the interpretation model are assumed to represent the parameters of the real system S. [c19]

(iii) Validate the results of the interpretation. This can be achieved by using the parameters determined from part (ii) in the model to generate output

[c1] *Murat Çınar*: ~~average~~
[c2] *Murat Çınar*: Based upon the explanation you gave about the pressure decline recently, I am not sure if this statement is correct.
[c3] *Murat Çınar*: ~~which~~
[c4] *Murat Çınar*: ~~to~~
[c5] *Murat Çınar*: ~~Here our hope is that the model chosen will produce an output signal to a given input which is as close as possible to that of the actual system.~~
[c6] *Murat Çınar*: *Text added.*
[c7] *Murat Çınar*: ~~With~~
[c8] *Murat Çınar*: ~~can~~
[c9] *Murat Çınar*: ~~which~~
[c10] *Murat Çınar*: ~~. However~~
[c11] *Murat Çınar*: ~~Such parameters can be~~
[c12] *Murat Çınar*: ~~the~~
[c13] *Murat Çınar*: ~~problem~~
[c14] *Murat Çınar*: ~~. It is~~
[c15] *Murat Çınar*: *Text added.*
[c16] *Murat Çınar*: *Text added.*
[c17] *Murat Çınar*: ~~direct~~
[c18] *Murat Çınar*: ~~direct~~
[c19] *Murat Çınar*: I think we should discuss this phrase. Does the real system have any parameters? I do not think so... This is something conceptual we need to think about

signals for the entire range of [c20]the test and by comparing these outputs with the [c21]physical measurements.

[c20]*Murat Çınar*: *Text added.*

[c21]*Murat Çınar*: ~~measured ones~~

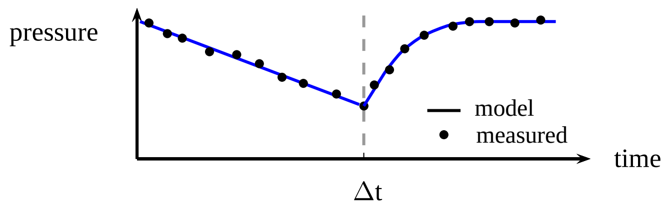

Fig. 1.3. Parameters estimated based on the analysis of buildup data.

[c1]Now we consider single phase flow in a cylindrical reservoir produced by a well at the center. The[c2]partial differential equation (PDE) describing the flow is given by,

$$\frac{1}{r}\frac{\partial}{\partial r}\left(\frac{kr}{\mu}\frac{\partial p}{\partial r}\right) = \phi c_t \frac{\partial p}{\partial t} \tag{1.3}$$

or if k, μ are constant,

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial p}{\partial r}\right) = \frac{\phi c_t \mu}{k}\frac{\partial p}{\partial t} = \frac{1}{\eta}\frac{\partial p}{\partial t} \tag{1.4}$$

[c1]*Murat Çınar*: ~~To illustrate an example of direct and inverse problems, let's consider single phase flow in a closed cylindrical reservoir produced by a single well at the center.~~

[c2]*Murat Çınar*: ~~pd.E~~

[c3]$\eta = \frac{k}{\phi c_t \mu}$ is the hydraulic diffusivity[c4]; a measure of the [c5]speed at which a pressure disturbance [c6]propagates through the formation. If we specify, k, ϕ, c_t, μ, and the flow rate, then $p(r,t)$ is uniquely determined. This is an example for the [c7]forward problem.

Inverse problem, given q and p, [c8]helps us to

1. determine the PDE that describes the reservoir best
2. find k, ϕ, etc.

[c9]

[c3]*Murat Çınar*: ~~$\eta = \frac{\phi c_t \mu}{k}$~~

[c4]*Murat Çınar*: ~~which is~~

[c5]*Murat Çınar*: ~~rapidity with~~

[c6]*Murat Çınar*: *Text added.*

[c7]*Murat Çınar*: ~~direct~~

[c8]*Murat Çınar*: *Text added.*

[c9]*Murat Çınar*: ~~During the past ten years, a lot of work has been done to develop models to a wide variety of reservoir / well configurations such as fractures, layered reservoirs, multiple porosities (composite zones), fractured wells, slanted and horizontal wells, etc. Well testing literature is almost complete for single phase problems, but some work needs to be done for multi-phase problems and heterogeneous reservoir systems.~~

~~Recently, people are much focused on the model recognition problem and the computer-aided parameter estimation by using non-linear regression techniques. Pressure derivatives and~~

References

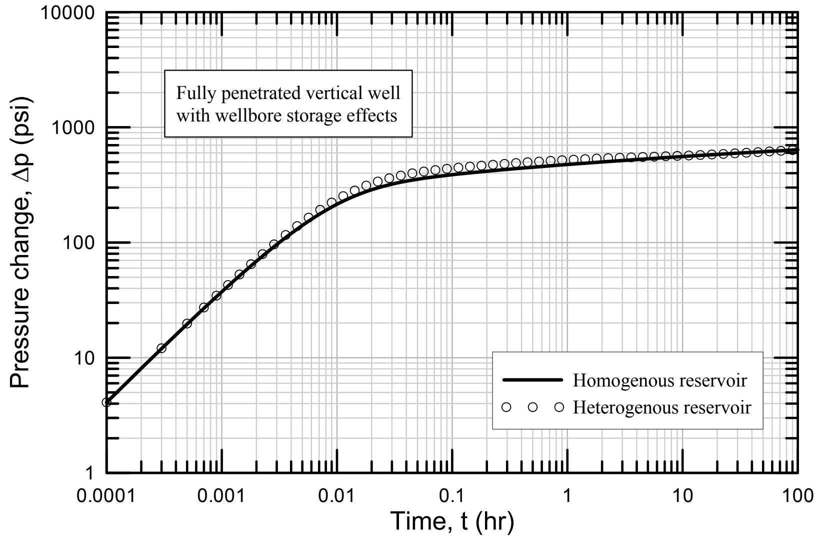

Fig. 1.4. Homogeneous vs heterogeneous reservoir, pressure difference .

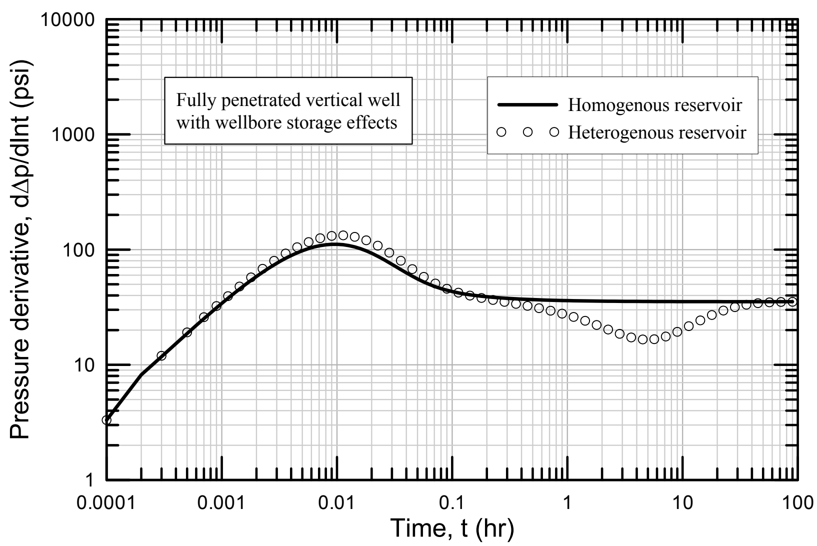

Fig. 1.5. Homogeneous vs heterogeneous reservoir - logarithmic derivative.

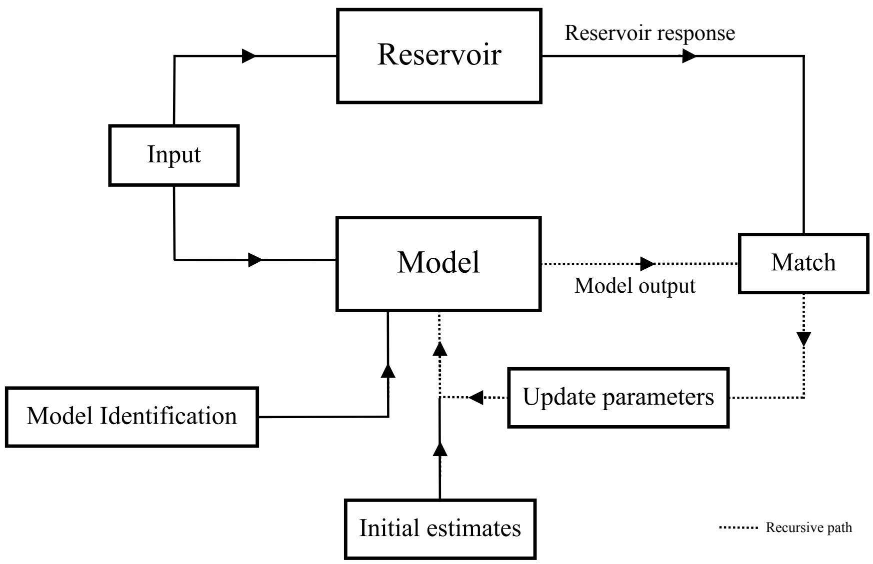

Fig. 1.6. Flow diagram of computer aided parameter estimation.