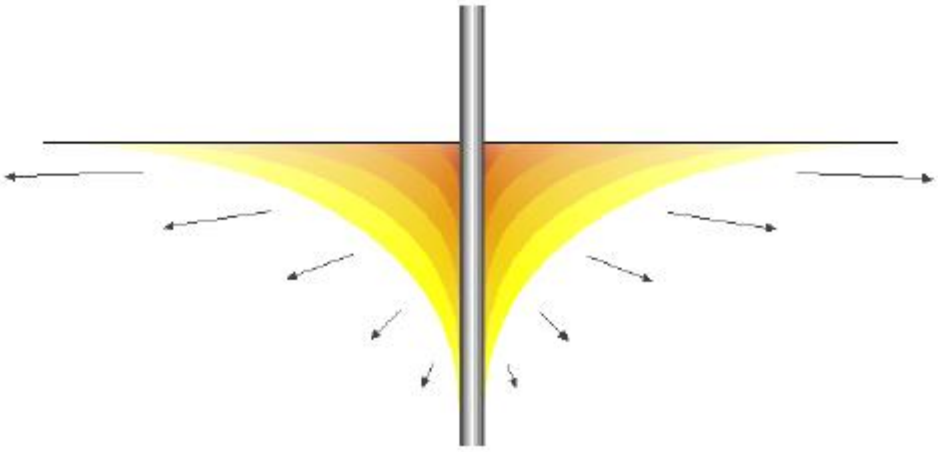
Advanced Pressure Transient Analysis



Well Test Analysis of Composite Reservoirs

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Outline

- Introduction
- Composite reservoir models
- Analysis of data

Introduction

$$r_{we} = r_w e^{-S}$$

$$S = \left(\frac{k}{k_S} - 1 \right) \ln \frac{r_S}{r_w}$$

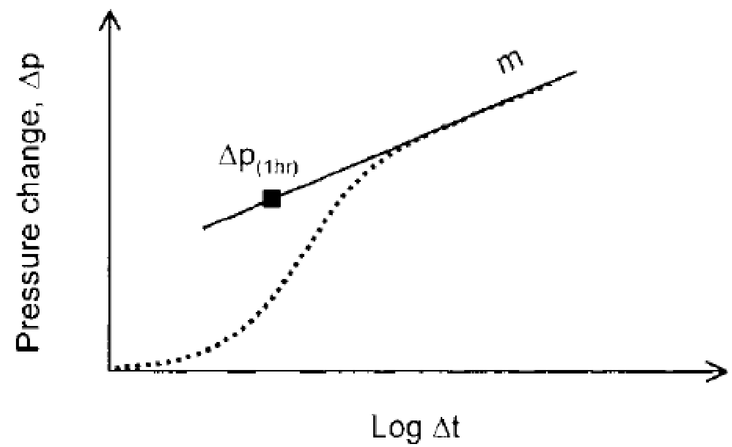


Figure 1.9. Radial flow regime. Specialized analysis on semi-log scale.

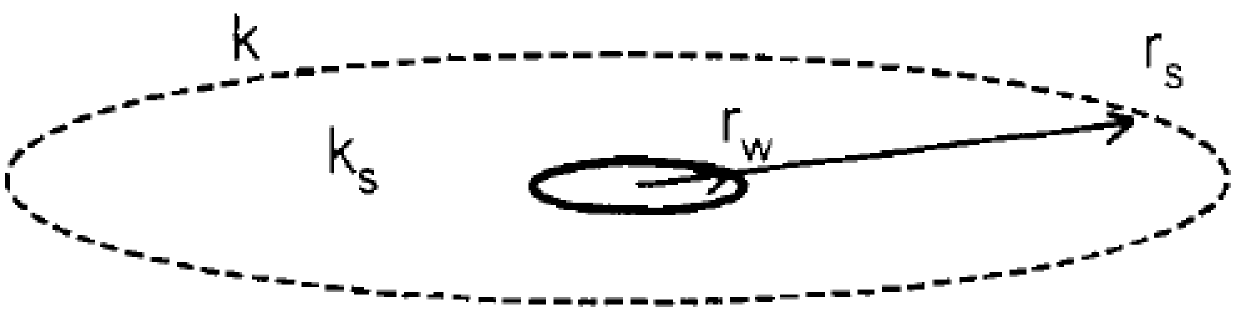


Figure 1.8. Flow through a circular reservoir region.

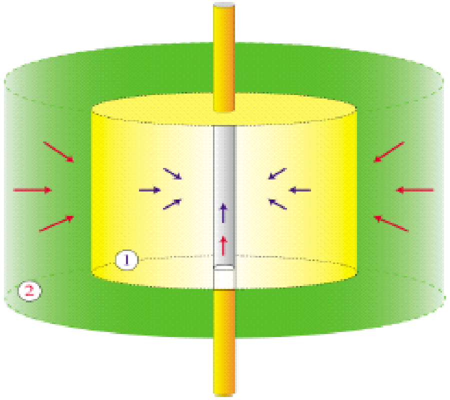
$$p_{w,S} - p_{w,S=0} = \frac{141.2qB\mu}{k_S h} \ln \frac{r_S}{r_w} - \frac{141.2qB\mu}{kh} \ln \frac{r_S}{r_w} \qquad (1.12)$$

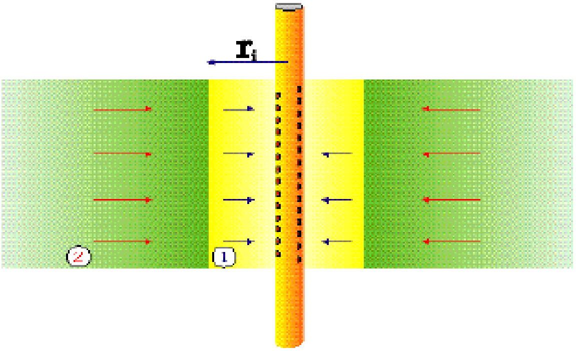
Introduction

The composite reservoir models consider two distinct media in the reservoir.

Each component is defined by a porosity and a permeability, and they are located in different reservoir regions.

Two geometries are considered for the interface between the reservoir areas.





- Radial composite systems have been studied from the early 1960's (Hurst, 1960; Loucks and Guerrero, 1961; Carter, 1966; Satman, 1980; Olarewaju, 1989)
- it is assumed that the well is at the center of a circular zone, the outer reservoir structure corresponds to the second element (Figure 4.51). This geometry is used to describe a radial change of properties, resulting from a change of fluid or formation characteristic.
  - Such change can be man-induced in case of injection wells and in some cases of damaged or stimulated wells. It can also be observed when oil and gas saturations vary around the wellbore, for example when the reservoir produces below bubble point or dew point.

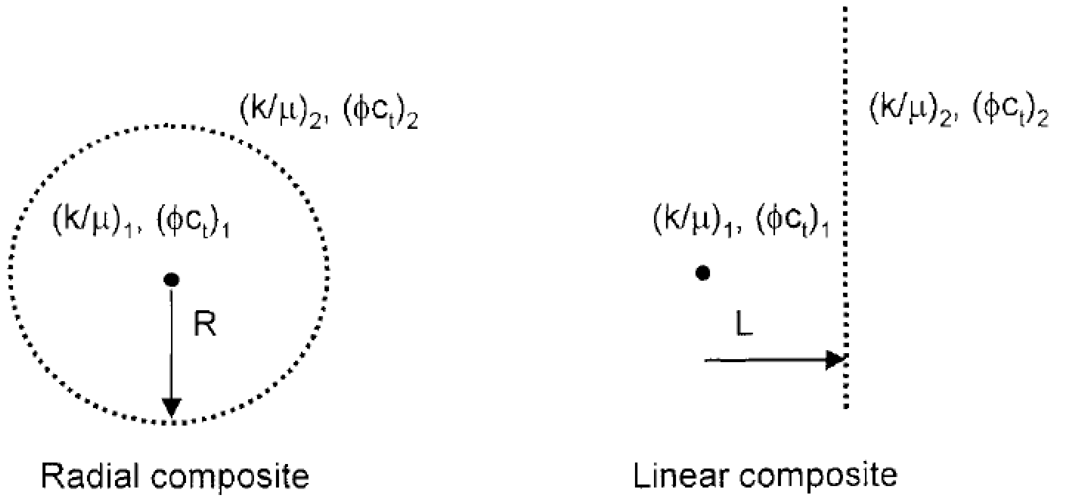


Figure 4.51. Models for composite reservoirs.

Radial Composite Reservoir Model

Composite Reservoir Assumptions

- ❑A discontinuity defines two distinct homogeneous regions in the infinite reservoir.
- ❑The interface is stationary, and it has no thickness.
- ❑ The mobility (k/μ and storativity (Φc_t) are different on each side, but the reservoir thickness h is constant.
- ❑The change of reservoir properties is abrupt, and there is no resistance to flow between the two reservoir regions.

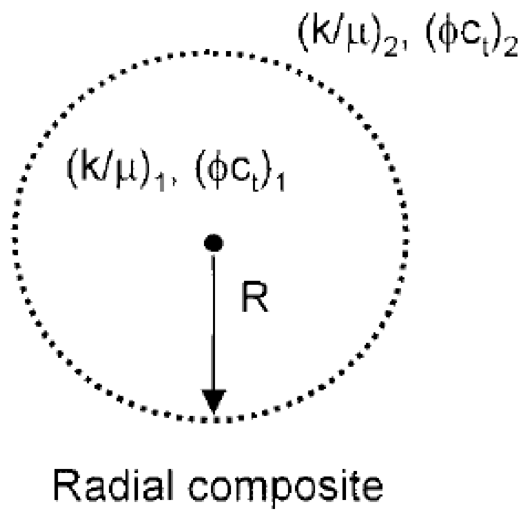


Figure 4.51. Models for composite reservoirs.

The well, affected by wellbore storage and skin, is located in the region 1: with the radial composite model, it is at the center of a circular zone of radius R. The characteristics parameters of the second region are defined with a subscript 2.

Radial Composite Reservoir Model

Definition

The changes of reservoir mobility,' (k/μ) and storativity (Φc_t) are expressed with the mobility **M** and storativity **F** ratios, defined as region 1 compared to region 2"

$$M = \frac{(k/\mu)_1}{(k/\mu)_2} \qquad (4.78)$$

$$F = \frac{(\phi c_t)_1}{(\phi c_t)_2} \qquad (4.79)$$

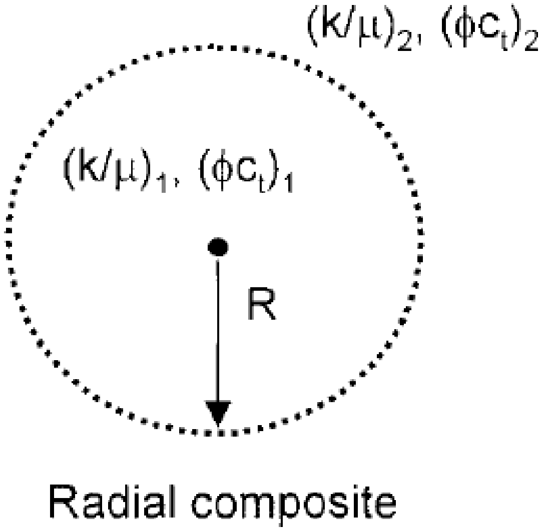


Figure 4.51. Models for composite reservoirs.

A mobility ratio **M** greater than 1 indicates a decrease of mobility from region 1 to region 2. A decrease of the storage is expressed with the ratio **F** greater than 1.

Radial Composite Reservoir Model

Dimensionless Variables

All dimensionless variables are expressed with reference to the parameters of the region 1 around the well.

$$p_D = \frac{k_1 h}{141.2 q B \mu_1} \Delta p \qquad (4.80)$$

$$t_D = \frac{0.000264 k_1}{(\phi \mu c_t)_1 r_w^2} \Delta t \qquad (4.81)$$

$$C_D = \frac{0.8936 C}{(\phi c_t)_1 h r_w^2} \qquad (4.82)$$

$$\frac{t_D}{C_D} = 0.000295 \frac{k_1 h}{\mu_1} \frac{\Delta t}{C} \qquad (4.83)$$

$$S = \frac{k_1 h}{141.2 q B \mu_1} \Delta p_{\text{skin}} \qquad (4.84)$$

$$R_D = \frac{R}{r_w} \qquad (1.21)$$

Radial Composite Reservoir Model

Behavior

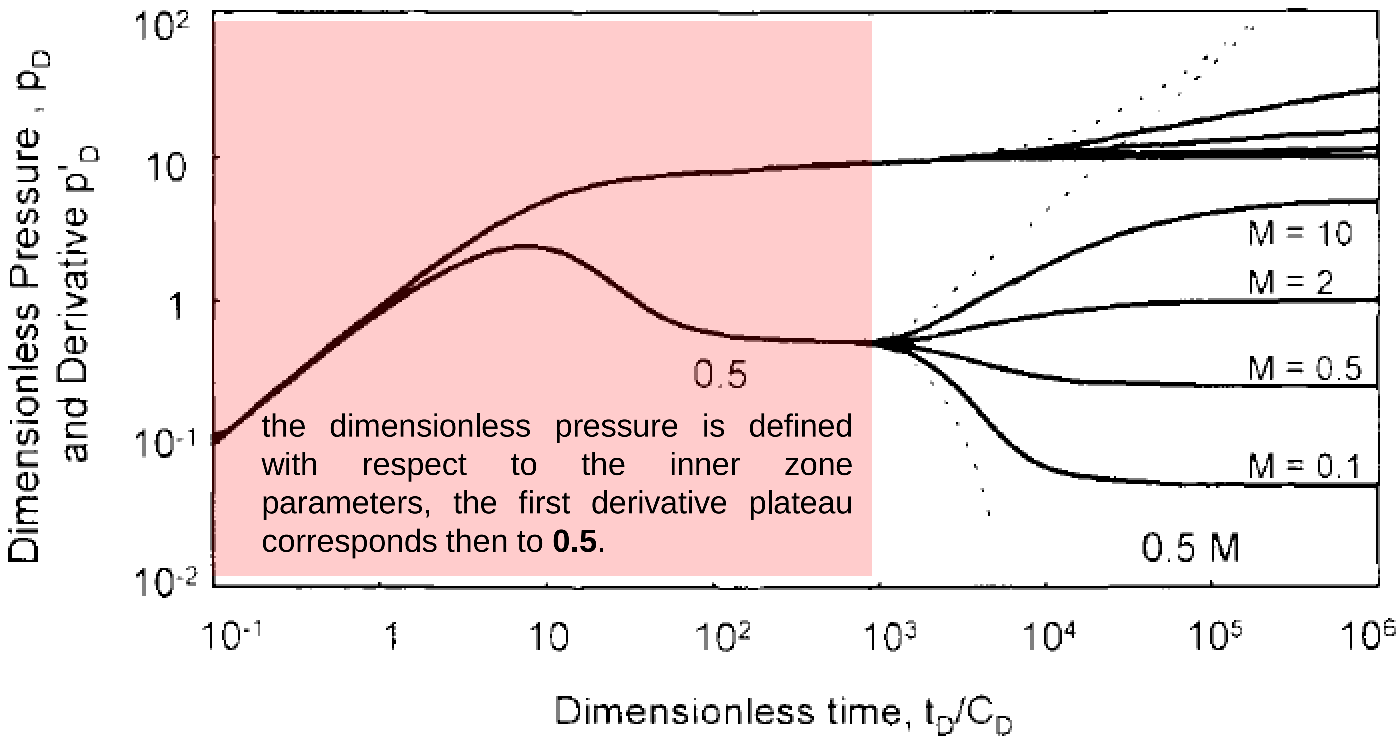
With the radial symmetry of the system, the two reservoir regions are seen in sequence:

1. First, the pressure response depends upon the inner zone characteristics, and the well behavior corresponds to a homogeneous reservoir response.
2. When the circular interface is reached, a second homogeneous behavior, corresponding to the outer region, is observed.

Radial Composite Reservoir Model

Behavior- Influence of M

In Figure 4.52, derivative responses are presented for different values of the mobility ratio **M**: the parameters of the well and of the inner zone are constant, the two reservoir regions have the same storativity (F = 1).



$$M = \frac{(k/\mu)_1}{(k/\mu)_2}$$

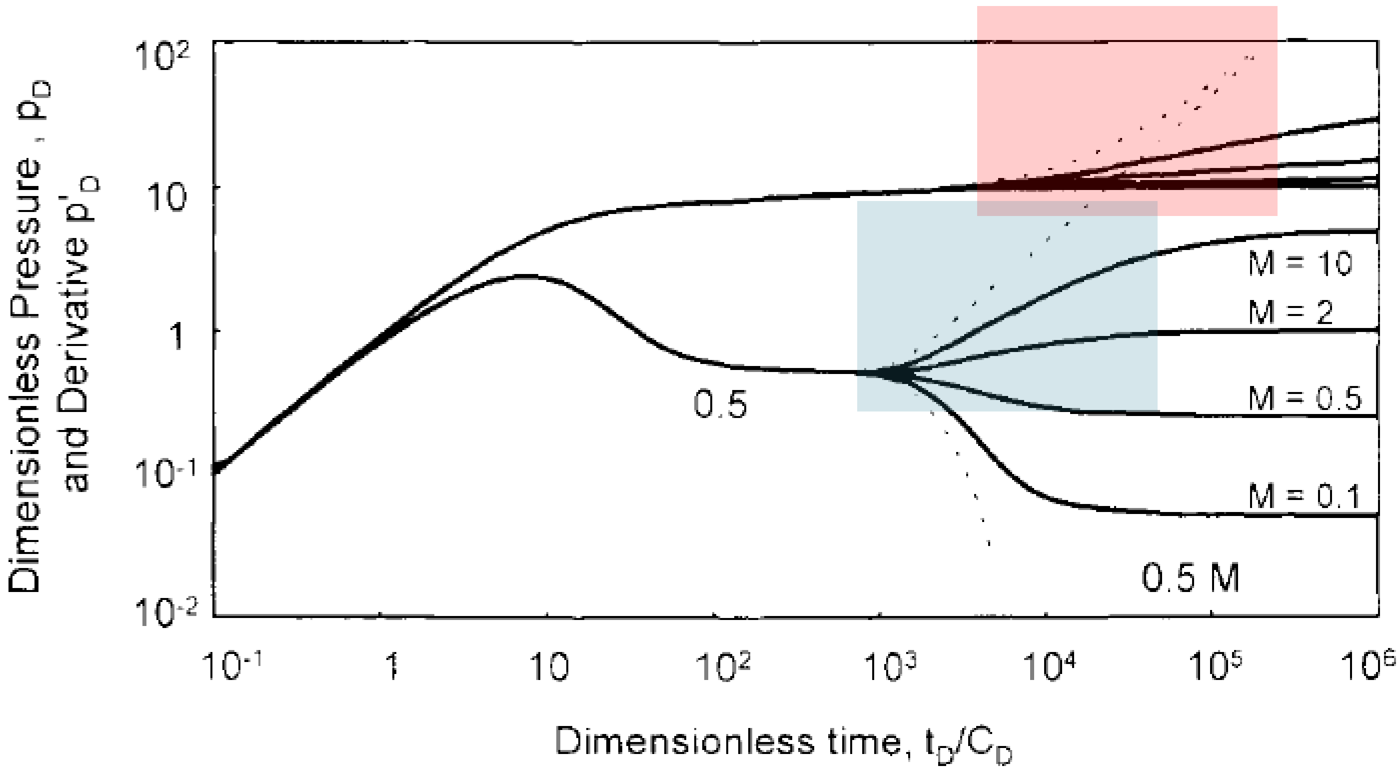
$$F = \frac{(\phi c_t)_1}{(\phi c_t)_2}$$

Figure 4.52. Log-log plot of radial composite responses, changing mobility and constant storativity. p_D versus t_D/C_D. $C_D = 100$, $S = 3$, $R_D = 700$, $M = 10, 2, 0.5, 0.1$, $F = 1$.

Radial Composite Reservoir Model

Behavior- Influence of M

The dotted derivative curves show the drawdown response of a well in a closed circle of same radius R_D): it illustrates the limiting case of a zero mobility in the outer zone.



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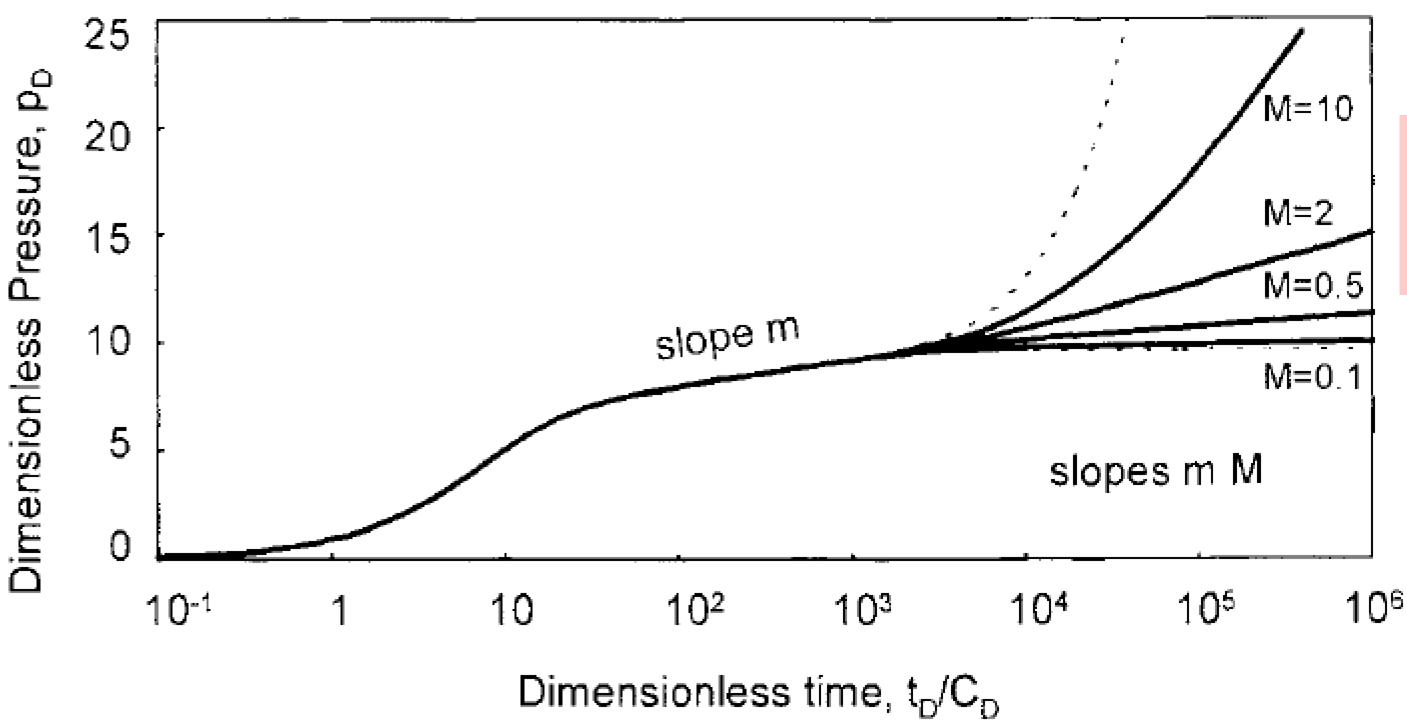
Radial Composite Reservoir Model

Behavior- Influence of M

The slope of the second line at late time defines the mobility of the outer region.



$$M = \frac{(k/\mu)_1}{(k/\mu)_2}$$

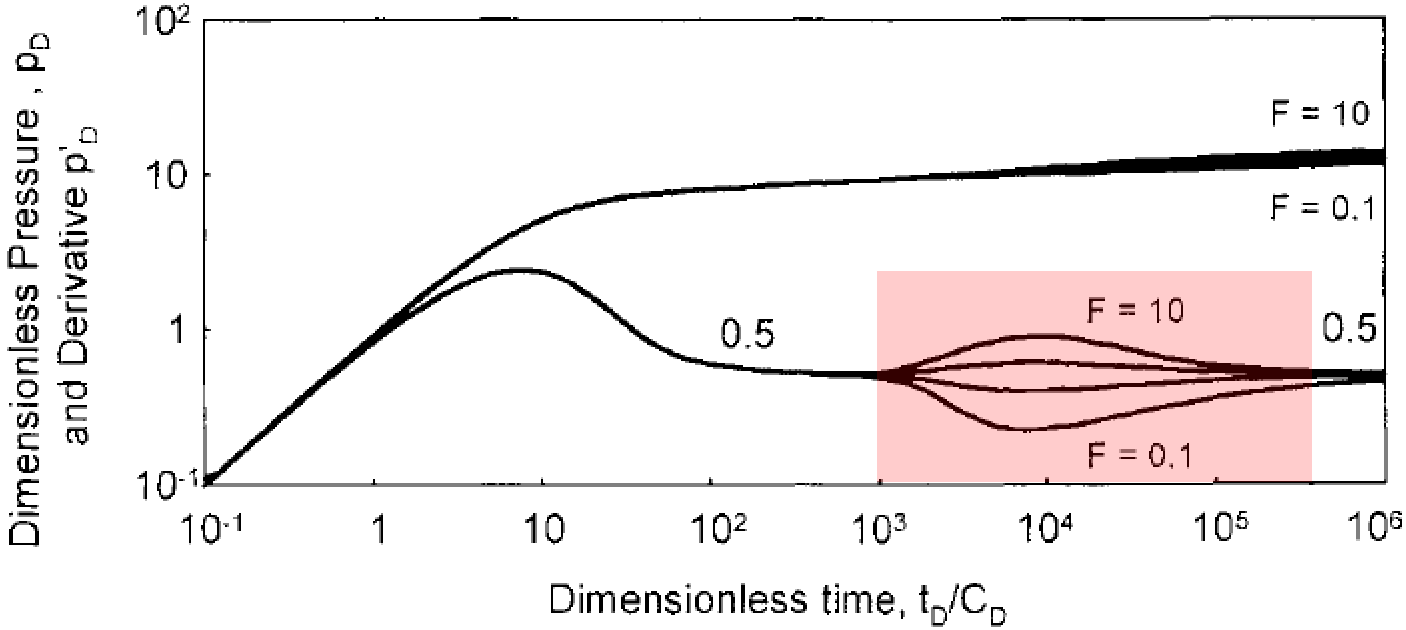
$$F = \frac{(\phi c_t)_1}{(\phi c_t)_2}$$

Figure 4.53. Semi-log plot of Figure 4.52 radial composite examples.
The two dotted curves correspond to the closed and the constant pressure circle solutions.

Radial Composite Reservoir Model

Behavior- Influence of F

F=0.1 (Valley): the response corresponds to an increase of storativity.
F=10 (Hump) :the response corresponds to a decrease of storativity.



$$M = \frac{(k/\mu)_1}{(k/\mu)_2}$$

$$F = \frac{(\phi c_t)_1}{(\phi c_t)_2}$$

Figure 4.54. Log-log plot of radial composite responses, constant mobility and changing storativity. p_D versus t_D/C_D. $C_D = 100$, $S = 3$, $R_D = 700$, $M = 1$, and $F = =10, 2, 0.5, 0.1$
The two pressure curves correspond to $F = 10$ and $F = 0.1$.

Radial Composite Reservoir Model

Behavior- Influence of F

When the storativity increases (curve F=0.1 of Figure 4.55), the transition between the two parallel semi-log straight lines tends to the horizontal as for a double porosity response.

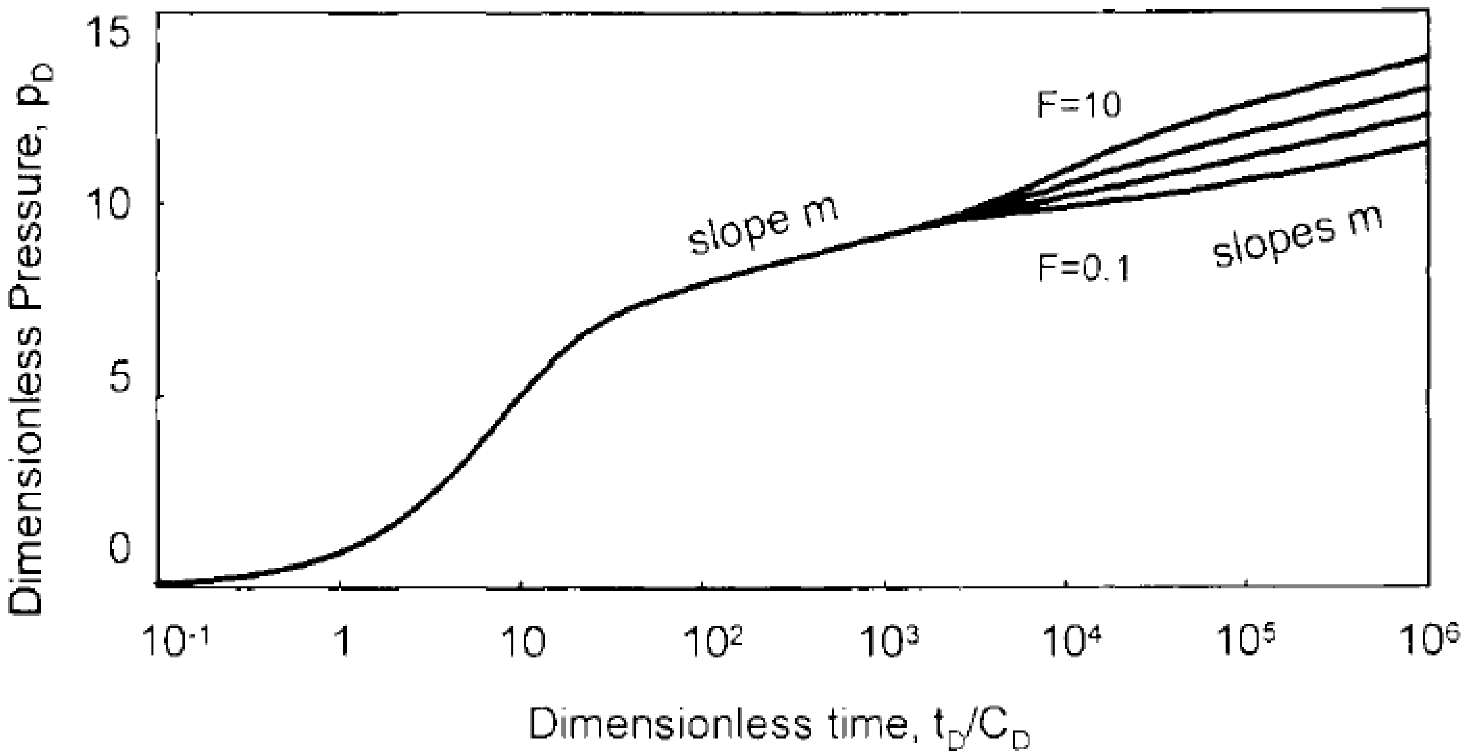
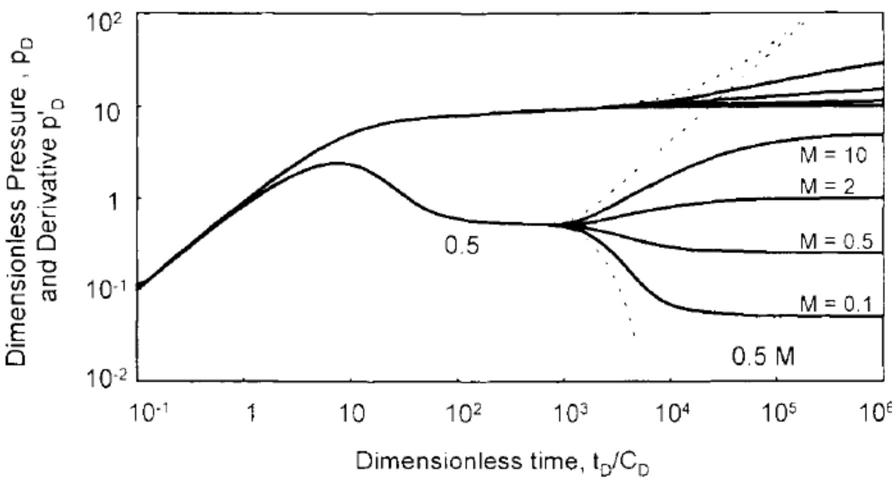


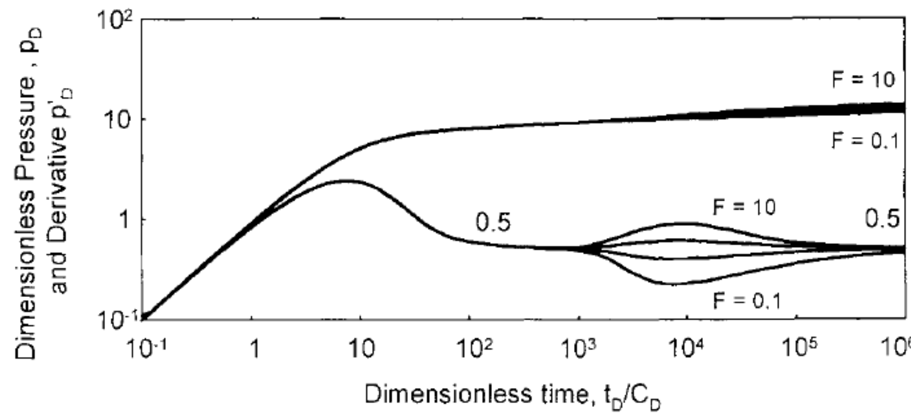
Figure 4.55. Semi-log plot of Figure 4.54 radial composite examples.

Radial Composite Responses

❑The duration of the first homogeneous regime is a function of the inner region radius: with a large R_D, the transition occurs later. Before the transition, the early time response corresponds to the behavior of a well with wellbore storage and skin in a homogeneous reservoir.

❑The shape of the transition is a function of M and F.





Semi-log Analysis

The first semi-log straight line describes the inner zone response.

$$\Delta p = 162.6\frac{qB\mu_1}{k_1 h}\left(\log\Delta t + \log\frac{k_1}{(\phi\mu c_t)_1 r_w^2} - 3.23 + 0.87S\right) \qquad (4.88)$$

The analysis of the first semi-log line provides the mobility of the inner zone, and the wellbore skin factor (also called S_w).

The second line, for the outer zone, is defined by:

$$\Delta p = 162.6\frac{qB\mu_2}{k_2 h}\left(\log\Delta t + \log\frac{k_2}{(\phi\mu c_t)_2 r_w^2} - 3.23 + 0.87S_T\right) \qquad (4.88)$$

From the second straight line, the outer zone mobility is estimated and, if the first line is also present on the response, the mobility ratio **M** is defined.

Semi-log Analysis

The total skin $\mathbf{S_T}$ is calculated from the second line and includes two components:

- the wellbore skin factor **S** and
- a radial composite apparent skin effect S_{Rc}, function of the mobility ratio M and the radius R_D of the circular interface

$$S_T = \frac{k_2 h}{141.2 q B \mu_2} \Delta p_{skinT}$$

The two components of S_T are defined as:

$$S_T = \frac{1}{M} S + \left(\frac{1}{M} - 1 \right) \ln R_D \qquad (4.91)$$

Semi-log Analysis

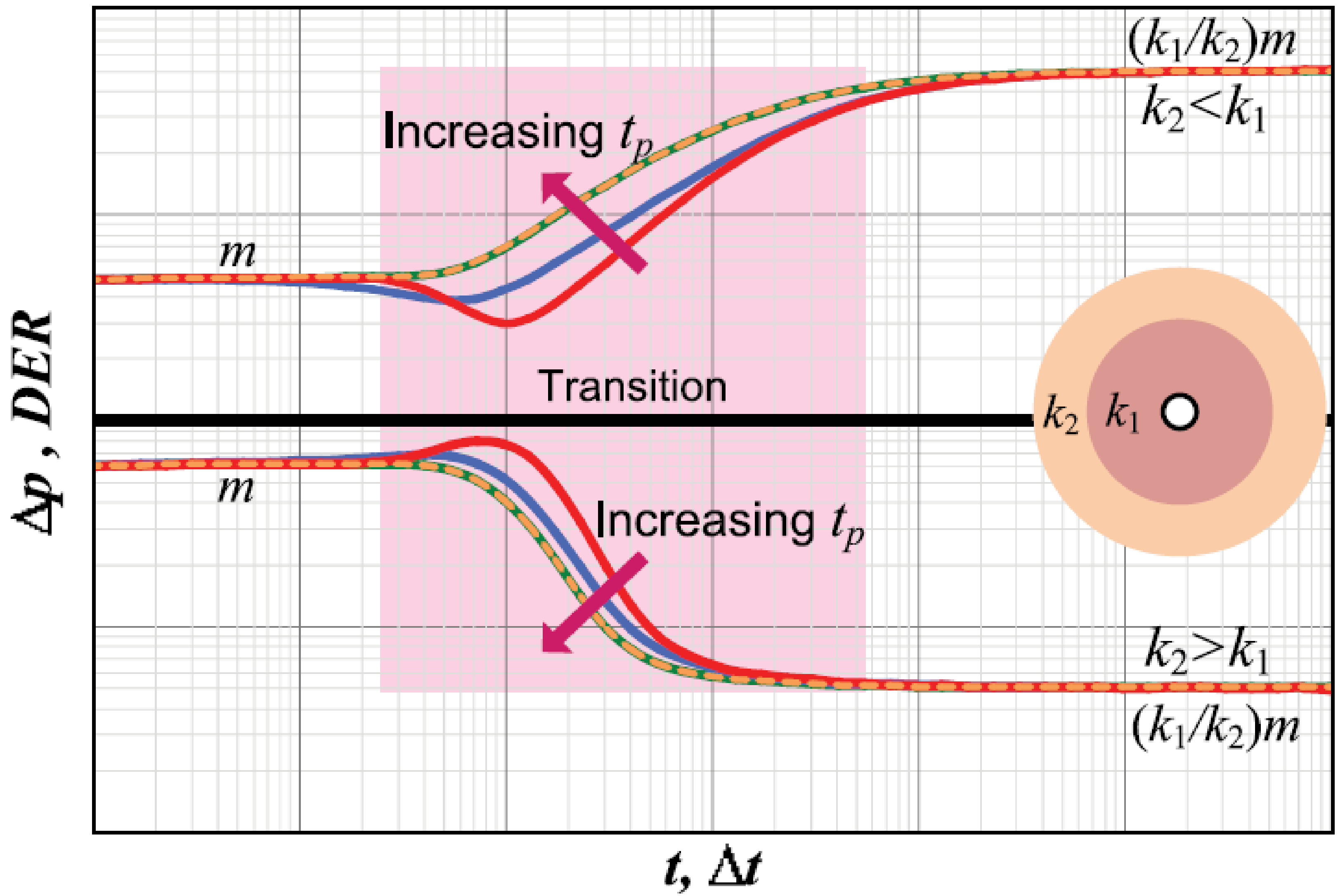
$$S_T = \frac{1}{M}S + \left(\frac{1}{M} - 1\right)\ln R_D \qquad (4.91)$$

The second term of Equation 4.91 is the radial composite apparent skin effect S_{RC}. It describes the influence of the inner zone during the late time homogeneous response.

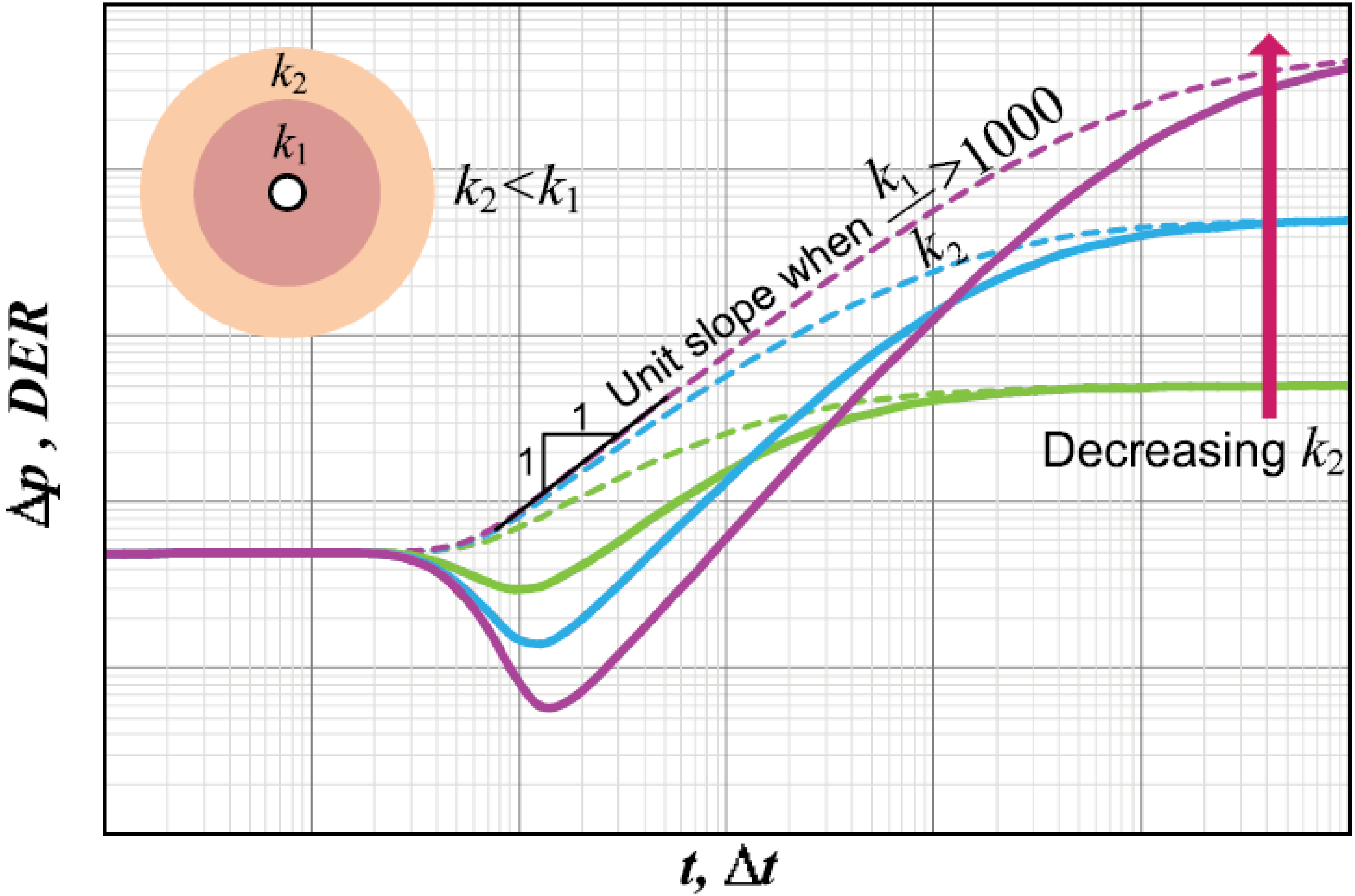
- ❑When the near wellbore mobility is higher than in the outer zone (M >1), the inner zone appears as a negative skin.
- ❑In the opposite case (M<I), a reduced mobility around the wellbore is equivalent to a well damage, and the apparent radial composite skin is positive.

When the two semi-log straight lines are clearly defined, the analysis provides **M**, **S** and, if the outer zone storativity is known, $\mathbf{S_T}$ can be calculated. The radius $\mathbf{R_D}$ of the circular interface between the two reservoir regions can then be estimated from **Equation 4.91**.

Composite Reservoir-t_p



Composite Reservoir-k_2



Composite Reservoir

- **Composite Reservoir:**
  - *DER* similar to no-flow boundary
  - *DER* transitions from one radial flow, m, to another radial flow, $(k_1/k_2)m$
  - Duration of transition depends on k_2 to k_1 contrast
  - Dip in *DER* during transition increases with k_1/k_2
  - As t_p increases, dip disappears