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SLUG TEST DATA ANALYSIS IN RESERVOIRS WITH DOUBLE POROSITY BEHAVIOUR

Khalid Mateen and Henry J. Ramey Jr.

Stanford University

ABSTRACT

Pressure analysis for a slug test which corresponds to the flow period of a Drill Stem test is extended to wells in reservoirs with double-porosity behaviour.

Solutions are obtained for either pseudo-steady state or transient interporosity flow. The distinctive specific features of both solutions are identified. Results presented are applicable to both naturally-fractured and layered reservoirs with the more permeable layer connecting to the wellbore.

Type curves based on the pseudo-steady or transient interporosity flow are presented. These type curves are similar to the existing homogenous single layer type curve with addition of interporosity flow lines indicating double-porosity behaviour.

INTRODUCTION

The slug test problem is posed by a formation with a pressure which is, at most, great enough to lift a column of reservoir fluid just to the surface of the earth. The initial production rate is high and gradually declines as the accumulating fluid in the drill string increases the back pressure.

The slug test was introduced in ground water hydrology by Ferris and Knowles in 1954. An analogous heat conduction test was reported by Jaeger (1956). In 1967, Cooper et al. presented a solution for a well of a finite diameter and showed the line source approximation of Ferris and Knowles to be valid for large times.

Neglecting inertial and friction effects the liquid column is assumed to be in static equilibrium with the wellbore. Slug test formulations based on liquid column height and that based on bottom hole pressure were separately proposed. Liquid column height is measured in ground water hydrology, whereas bottom hole pressure is measured in petroleum industry.

In 1972, Ramey and Agarwal presented a detailed derivation for the DST problem with skin effect. These authors obtained a solution to the problem in the form of an inversion integral by Laplace transformation. Ramey, Agarwal and Martin (1975) correlated the solution for DST problem using a wellbore storage coefficient and dimensionless time based on effective wellbore radius, a technique used by Earlougher and Kersh (1974) in conventional well testing. More detail on pertinent literature has been presented by Mateen(1983).

Extensive work has been done in recent years to explain the transient pressure behaviour of naturally-fractured or fissured reservoirs. Such reservoirs have homogenously distributed regions of primary and secondary porosity. One medium(fissure) presents a high conductivity and drains the reservoir fluid to the well, the other(matrix) has a much lower conductivity and feeds only to the fissure medium. They are termed two-porosity reservoirs. Naturally-fractured reservoirs and layered reservoirs with only the more permeable layer conducting to a wellbore exhibit the same double porosity behaviour. Warren and Root(1963) mathematically modelled such reservoirs. They assumed pseudo-steady interporosity flow and showed interporosity flow parameter λ, and a storativity ratio ω, were sufficient to characterize the flow model. In this study diffusivity equations for matrix and fissures were formulated and combined assuming either pseudo steady state or transient interporosity flow.

The characteristic double-porosity diffusion equation was then coupled in Laplace space with wellbore pressure through inner boundary conditions of a steady- state pressure drop occuring at the sand face (skin effect), and a wellbore storage effect. Type curves based on either pseudo-steady state or transient interporosity flow were developed.

PROBLEM SOLUTION

The details of the problem solution are presented by Mateen (1983). Only the reults will be discussed here. However it is necessary to define useful dimensionless groups, they are defined as:

$$p_{wfD} = \frac{p_i - p_{wf}}{p_i - p_o} \quad \ldots\ldots\ldots(1)$$

$$t_D = \frac{k_f t}{[\,(\phi Vc_t)_f + (\phi Vc_t)_m\,]\,\mu r_w^2} \quad (2)$$

$$r_D = \frac{r}{r_w} \quad \ldots\ldots\ldots(3)$$

$$C_D = \frac{C}{2\pi h[\,(\phi Vc_t)_f + (\phi Vc_t)_m]r_w^2} \quad \ldots(4)$$

$$\omega = \frac{(\phi Vc_t)_f}{[\,(\phi Vc_t)_f + (\phi Vc_t)_m]} \quad \ldots(5)$$

$$\frac{t_D}{C_D} = \frac{2\pi k_f h\ \Delta t}{\mu\ C} \quad \ldots\ldots(6)$$

$$\lambda = \frac{\alpha\ k_f\ r_w^2}{k_m} \quad \ldots(7)$$

where "α" is interporosity shape factor, defined by Warren and Root (1956) as

$$\alpha = \frac{4\ n\ (n+2)}{l} \quad \ldots\ldots(8)$$

where "n" is the number of normal subsets of fissures and "l" is a characteristic dimension of the matrix.

The behaviour at early and late times is that of a homogenous reservoir and corresponds to two different curves on the type curves introduced by Ramey et al.(1975). At intermediate times for the pseudo-steady interporosity flow model the pressure response depends on λe^{-2S}. At intermediate times for transient interporosity flow the pressure response depends upon a dimensionless parameter β.

For slab-shaped matrix blocks, β is given by:

$$\beta = \frac{3\, C_D\, e^{2S}}{\lambda\, e^{-2S}} \qquad .....(9)$$

For spherically-shaped matrix blocks, β is equal to:

$$\beta = \frac{3\, C_D\, e^{2S}}{5\, \lambda\, e^{-2S}} \qquad ....(10)$$

Type Curve Analysis For Pseudo Steady State Interporosity Flow

The interporosity flow effect for a double-porosity reservoir with λe^{-2S} as the governing parameter is shown in Fig. 1

The corresponding pressure response in a Slug test for a well in double-porosity reservoir is therefore obtained by superposing the curves of early and late homogenous behaviour, with the curves of intermediate interporosity flow behaviour, and is presented in Fig. 2. A typical result for a wellbore pressure in a two porosity reservoir is given in Fig. 3. At early times, production comes from the fissure system with $C_D = C_{Df}$. As the matrix starts feeding into the fissures, pressure leaves the $C_D e^{2S}$ curve and follows λe^{-2S} curve, until production comes from the entire system. At this stage pressure follows a new $C_D e^{2S}$ with $C_D = C_{Df+m}$, below the first curve

Assuming $(\phi h c_t)$ and the wellbore storage coefficient (C) are known, a semilog or a log-log type curve analysis of pressure response can yield all the system parameters. Transmissivity can be obtained from the time match, skin factor(S) from $C_D e^{2S}$ match, λ from λe^{-2S} match, and storativity ratio ω, from the ratio of $C_D e^{2S}$ value of last curve to $C_D e^{2S}$ value of the first curve. Determination of ω is not always possible, specially when pressure follows the transition curve from very early times.

Type Curve Analysis For Transient Model Interporosty Flow Model

As for the pseudo-steady state interporosity model, the mechanism of fluid flow in double-porosity reservoirs with transient interporosity flow involves three successive flow regimes. At early times, there is a homogenous system behaviour with only fissures contributing to the flow. At intermediate times, a transition occurs and the matrix contributes progressively. Response is described by one of the β curves in Fig. 4. At late times, the behaviour is again homogenous with both matrix and fissures contributing. A typical two-porosity case with the transient flow assumption is portrayed in Fig. 5. Type curves for the transient interporosity flow model are obtained by superposing curves of transition curves from Fig. 4 on the homogenous system type curves of Ramey et al.(1975)

A semi-log or a log-log type curve analysis can be used to evaluate reservoir parameters in the same way as for the pseudo-steady state model. However, during the transition period, pressure follows a curve corresponding to some β value. Determination of the interporosity flow parameter β, therefore, requires additional knowledge about the geometry of the matrix blocks.

Knowledge that either the reservoir is fissured or layered can be obtained through logging, or other geological evidences.

Pseudo Steady State Model as compared to Transient Interporosity Flow Model

Both the pseudo-steady state and transient models yields the same flow pattern: fissure-homogenous at early times, transition at intermediate times, and total-homogenous at late times.

The principal difference between the two models is the shape and duration of the transition curve. The difference is more pronounced on the left side of the type curve, that is for large values of λe^{-2S} Transition curves for the pseudo-steady state model in this range of time are steeper than for the transient interporosity flow model. This fact causes the transition duration to be shorter than for transient inter porosity flow model. Also the transition from the early and late time curves is less smooth than that for the transient model. For small values of λe^{-2S}, the pressure response of these two models becomes almost identical.

Results indicate that under certain ranges of values of ω and λ the double porosity effects are not distinguishable from those of a homogenous reservoir. Pressure in both pseudo steady state and transient interporosity flow models responds in a similar way to a given change in parameters ω and λ.

Nomenclature

c_t	:	total compressibility, atm
C	:	wellbore storage constant, cc/atm
C_D	:	dimensionless wellbore storage constant
h	:	formation thickness, cm
k_f	:	permeability of fissure, darcys
p_i	:	Initial pressure, psi
p_o	:	Cushion pressure, psi
p_{wf}	:	pressure in the fissure medium within the wellbore, atm
p_{wfD}	:	dimensionless pressure drop in the fissure medium within the wellbore
r	:	radial distance from the well, cm
r_w	:	radius of the wellbore, cm
S	:	dimensionless skin factor
t	:	time, sec
t_D	:	dimensionless time
V	:	ratio of volume of one porous system to bulk volume
α	:	interporosity shape factor, cm^2
β	:	interporosity flow group
λ	:	interporosity flow parameter
μ	:	viscosity, cp
ω	:	storativity ratio
ϕ	:	porosity of the medium, fraction

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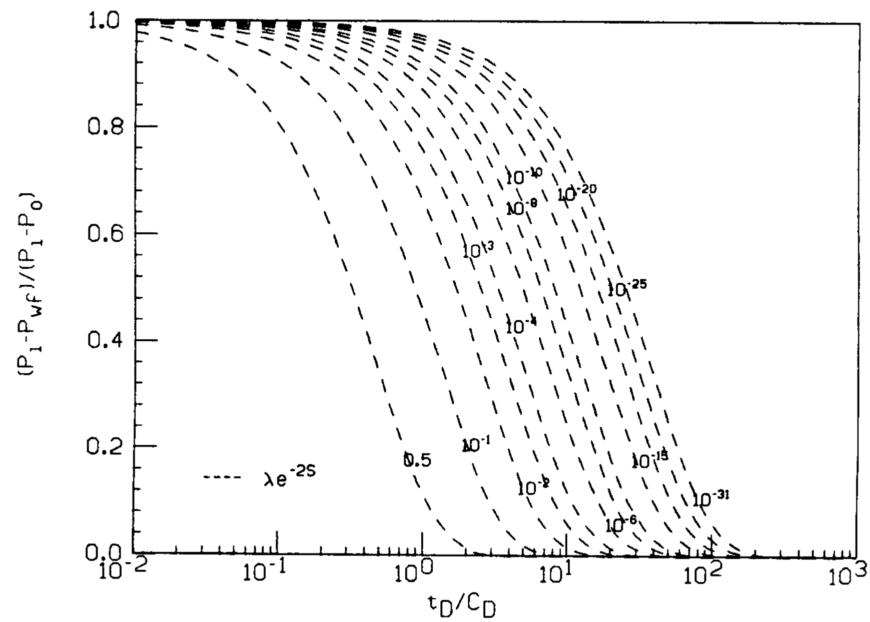

Figure 1: Transition pressure in double porosity reservoir (PSS) (Semi-log)

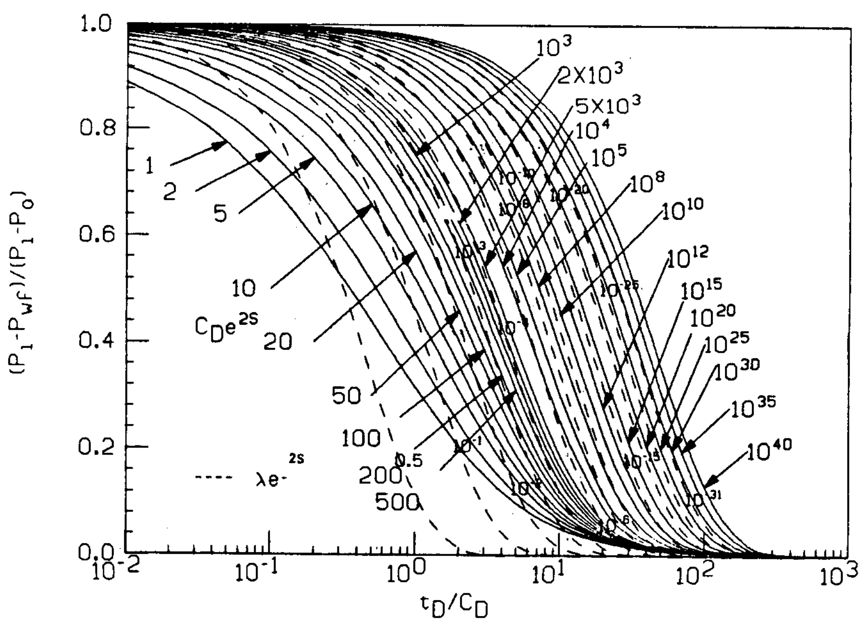

Figure 2: Semi-log double porosity type curve (PSS)

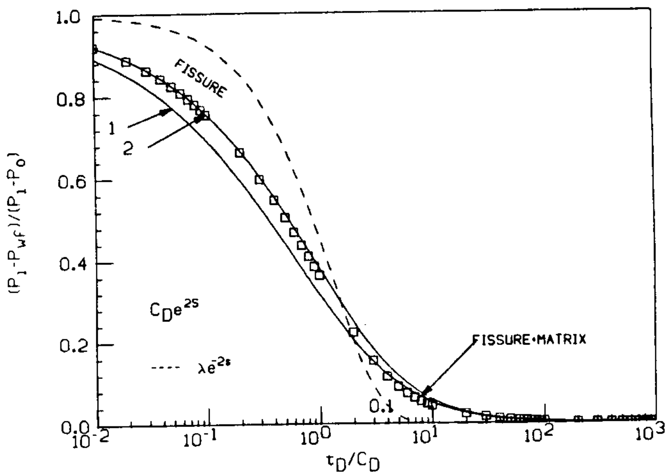

Figure 3: Example of semi-log double porosity behavior (PSS)
(ω = 0.5, $\lambda * e^{-2S}$ = 0.1)

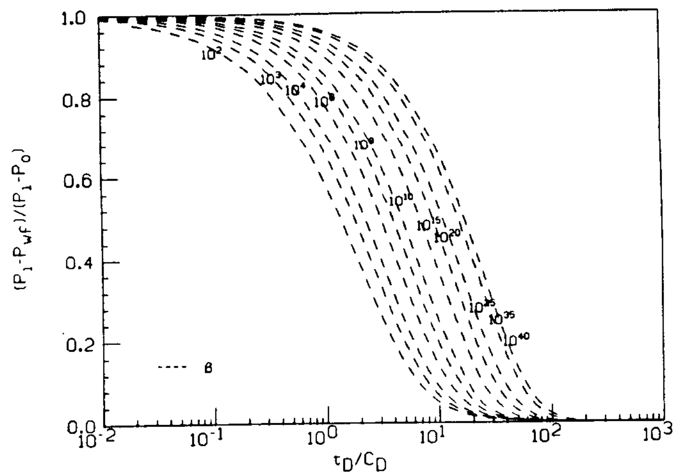

Figure 4: Transition pressure in double porosity reservoir
Transient Model

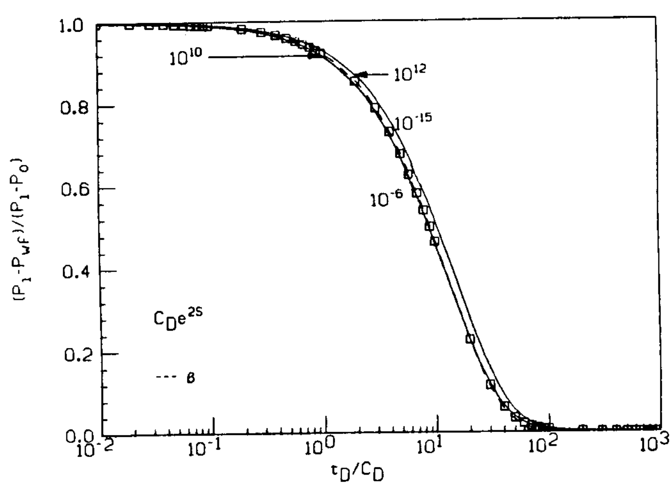

Figure 5: Example of semilog double porosity behavior (Transient)
(ω = 0.01, β = 3.0 D + 21)