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Pressure transient behavior analysis in a dual-porosity reservoir with partially communicating faults

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ABSTRACT

Many oil bearing fractured reservoirs are faulted reservoir (Abbaszadeh M.D. and Cinco-Ley H., 1995). Hydraulic characterization of these faults is essential for field-scale development design. In this study, a mathematical model is presented that describes the pressure transient behavior of a reservoir separated by a partially communicating fault (PCF). In the math model, vertical well is treated as an infinite line source; and PCF is treated as an infinitely long, vertical semi-permeable barrier. Based on the Warren Root model, transient pressure model of a two-region-infinite-composite dual-porosity reservoir with PCF has been established. Two regions on both sides of the fault have distinct properties. Given a line source, constant-rate well in a composite reservoir, analytical solutions of pressure transient behavior are obtained using one Fourier space transformation and time-space Laplace transformation. In addition, derived type curves and sensitivities of relating parameters are discussed. Model presented in this paper could be directly applied for well test analysis in a dual-porosity reservoir with PCF.

1. Introduction

Faults in a hydrocarbon-bearing reservoir may be either sealing or non-sealing. A sealing fault will completely impede fluid flow laterally and may act as a trap for hydrocarbon accumulation. Due to juxtaposition of two permeable fault blocks, PCF will allow some degree of lateral fluid flow along or cross fault surfaces. The permeability of a fault plane may be different from permeability of adjacent formations. Depending on the permeability contrast between fault and formation, fluid may flow along or across fault plan to establish communication between two adjacent fault blocks. In general, fluid flow through finite-conductive fault have mixed behavior of flow along and across the fault plane.

The influence of a PCFon interference testing was first studied by Stewart et al. (1984), who modeled the fault zone as a linear, vertical semi-permeable barrier with negligible capacity. Bixel et al. (1963) presented a mathematical model of a well located near a linear PCF in an infinite reservoir where the PCF was considered as a linear discontinuity. However, the model is only limited to reservoir with significant contrast of rock and petrophysical properties such as thickness, porosity and permeability. Cinco and Samaniego (1976, 1981) studied the transient flow behavior of a well near an infinite conductivity vertical, nonintersecting, natural fracture in an infinite slab reservoir based on point source function. Streltsova and McKinley (1984) studied the impact of PCF on the well interfere test using numerical simulation by considering fault as a linear, vertical and semi-permeable boundary and neglecting the reservoir capacity.

Later, Yaxely (1987) presented a mathematical model that captures the effect of a PCF on transient pressure behavior. The well is modeled as an infinite line source and the PCF as an infinitely long, vertical and semipermeable barrier. These solutions considering PCF improved the design and analysis of interference tests. Ambastha and Sageev (1987, 1989, 1990) modeled a linear fault as an infinitesimal thickness skin boundary. Analytical solution of a line-source, constant-rate well in a composite reservoir is obtained with one Fourier space transformation and time-space Laplace transformations.

Above models only allow porous fluid flows laterally across the fault planes. However, in reality, in porous media, fluid often flows both along and across the fault plane. Particularly, when permeability along the fault plane is larger than the adjacent

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reservoir permeability, the fluid flow along the fault plan is not negligible. Abbaszadeh and Cinco-Ley (1995) presented a general analytical solution of pressure transient distribution in a reservoir with an active well near a nonintersecting finite-conductivity fault. However, the model neglects the compressibility of the fluid within the fault plane; the solution is complicated; and the accuracy of the result cannot be guaranteed. Zhang and Liu (2012) proposed a model of pressure transient behavior of a reservoir with a normal fault, double porosity system and inclined well based on the point source function. Zhang et al. (2012) published an analytical solution for the pressure response of a slanted well in a slab reservoir with an impermeable fault. Based on the basic-point-source-solution in an infinite space, the basic-point-source-solution was obtained by using mirror image principle. Ezulike and Igbokoyi (2012) illustrated that, in a composite reservoir with leaky fault, horizontal well interference tests could be analyzed using Tiab's direct synthesis and curve making techniques.

From geological core and outcrop observation, PCFs are often observed in the dual-porosity reservoir. However, untill now, the studies on dual-porosity reservoir with PCF are rarely reported. In this paper, mathematic models are established to describe Pressure Transient Behavior in dual-porosity reservoir with PCF. The solution of the model is first derived by using the Laplace and Fourier transformation. Subsequently, transient pressure type curves are generated; and four key factors impacting type curves are discussed.

2. Mathematical model

In this paper, a composite dual-porosity reservoir with two regions separated by a PCF is studied. Interface skin factor is introduced in the mathematical model of dual-porosity reservoir with PCFs. Two reservoir regions on both sides of the fault may have different diffusivities and transmissivities; and fault resistance to fluid flow is modeled as a thin skin (Hurst, 1953; Van Everdingen, 1953). The presence of boundary skin is represented by a pressure discontinuity at the boundary (Ambastha and Ramey, 1990). The assumptions are listed below (Cai and Yu, 2011):

(1) Reservoirs on the both sides of semi permeable boundary have following features: each reservoir has dual-porosity system (following Warren and Root, 1963); the permeability and porosity in the two reservoirs can be different and do not vary with pressure.
(2) Single phase fluid flow is of slight compressibility and constant viscosity and follows Darcy's law.
(3) The reservoir thickness of two adjacent fault blocks can be different.
(4) Active well is treated as a constant production rate line source.
(5) Wellbore storage and skin effect are considered.
(6) Boundary skin is modeled the same way as Ambastha and Ramey (1990). To calculate the transmissibility of fault plane, boundary skin is used to model pressure discontinuity at the fault plane. The larger the boundary skin, the poorer the fault is connected.
(7) Gravity and capillary effects are negligible.

In two dimension space, reservoir with PCFs can be modeled as a linear discontinuity where boundary skin exists in its nearly vertical plane (Kuchuk and Habashy, 1997). As shown in Fig. 1, an infinite conductive well is located in region I. The compressibility of the fluid is constant. Fluid only flows horizontally; no fluid flows in the vertical direction.

Two regions have both matrix and fracture system; and the fluid in matrix only flows to the fracture system and not to the wellbore (Cinco and Meng, 1988). Fluid in fracture can flow directly to the wellbore. The flow between matrix and fracture system is pseudo steady flow. In any location of reservoir, there exist matrix pressure p_{m} and fracture pressure p_{f}.

2.1. Establishment of mathematical model

According to above assumptions, active well is a line source with a constant production rate q, the diffusivity equation for an idealized composite dual porosity infinite reservoir as shown in Fig. 1(c) is:

At region I ($x > 0$), for the fracture system, the diffusivity equation of fluid flow in the fracture system incorporating the source item can be described by the following equation (Guppy et al., 1981, 1982):

$$\frac{k_{f1}}{\mu_1}\left(\frac{\partial^2 p_{f1}}{\partial x^2}+\frac{\partial^2 p_{f1}}{\partial y^2}\right)-\frac{q}{h_1}\delta(x-a)\delta(y-b)+\alpha\frac{k_{m1}}{\mu_1}\left(p_{m1}-p_{f1}\right) = \left(\phi_f C_{tf}\right)_1\frac{\partial p_{f1}}{\partial t} \tag{1}$$

According to the assumption, the fluid flow in the matrix system obeys the Warren and Root dual porosity model, and follows the pseudo-state-interporosity flow. So the diffusivity equation in the matrix system including the interporosity from the matrix into fracture is

$$(\phi_m C_{tm})_1\frac{\partial p_{m1}}{\partial t}+\alpha\frac{k_{m1}}{\mu_1}\left(p_{m1}-p_{f1}\right)=0 \tag{2}$$

At region II, $x < 0$:

$$\begin{cases}\dfrac{k_{f2}}{\mu_2}\left(\dfrac{\partial^2 p_{f2}}{\partial x^2}+\dfrac{\partial^2 p_{f2}}{\partial y^2}\right)+\alpha\dfrac{k_{m2}}{\mu_2}\left(p_{m2}-p_{f2}\right)=\left(\phi_f C_{tf}\right)_2\dfrac{\partial p_{f2}}{\partial t}\\ (\phi_m C_{tm})_2\dfrac{\partial p_{m2}}{\partial t}+\alpha\dfrac{k_{m2}}{\mu_2}\left(p_{m2}-p_{f2}\right)=0\end{cases} \tag{3}$$

where δ is the delta function denoting the constant-rate line-source well; $\alpha\frac{k_{mi}}{\mu_i}(p_{mi}-p_{fi}), i=1,2,$ is inter porosity flow rate per unit volume from the matrix to the fracture; α is the shape factor (Zhao et al., 2013).

The initial condition is:

$$p_{f1}(x,y,0)=p_{f2}(x,y,0)=p_{m1}(x,y,0)=p_{m2}(x,y,0)=p_i \tag{4}$$

The boundary condition is:

$$p_{f1}(\infty,y,t)=p_{f2}(-\infty,y,t)=p_{f1}(x,\pm\infty,t)=p_{f2}(x,\pm\infty,t)=p_i \tag{5}$$

The connection condition is:

$$\frac{k_{f1}h_1}{\mu_1}\frac{\partial p_{f1}}{\partial x}=\frac{k_{f2}h_2}{\mu_2}\frac{\partial p_{f2}}{\partial x}, x=0 \tag{6}$$