Permeability Decay Evaluation for a Nonlinear Oil flow through Porous Media in a Wellbore Near a Sealing Fault through Green's Functions

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Abstract

This work proposes a new unsteady 2-D permeability pore pressure-dependent analytical model for a wellbore near a sealing fault, where the solution is based on an integro-differential solution of the Nonlinear Hydraulic Diffusivity Equation (NHDE) through Green's Functions (GF's). The model also considers the variation in the properties of the rock and the fluid present inside its pores.

Introduction

GF's-based analytical models have been proposed to solve the NHDE for isothermal flow through porous media and has shown close agreement, when compared to numerical flow simulator, (Barreto Jr. et al., 2011 and 2012), (Sousa et al., 2015) and (Fernandes et al., 2021a). This work proposes evaluating the permeability decay as a function of pore pressure, using a new coupled-pseudopressure model with variable permeability and GF's to solve NHDE with source near a sealing fault (**Fig.1**).

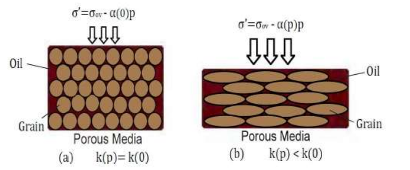

Fig.1: Permeability loss effect in porous media: (a) Initial condition (No production); (b) Pores collapsed, after several years of production.

Model Assumptions

The proposed model is based on combined asymptotic series expansion and GF for the sealing fault well-reservoir setting. The GF related to this problem can be found in Carslaw and Jaegger (1959). The solution is based on the following premises:

(1) Permeability pore pressure-dependent
(2) Mechanical hysteresis of porous media is negligible
(3) Small pressure gradient
(4) Newtonian fluid inside porous media
(5) Uniform net pay reservoir
(6) Skin and storage effects are not considered
(7) Well fully penetrates reservoir rock
(8) Deformable, homogeneous, linear elastic and isotropic reservoir
(9) Isothermal, single-phase flow in the porous media
(10) Homogeneous initial and boundary condition

Model Calibration

The model is calibrated through a numerical oil flow simulator. The calibration was performed by replacing the pressure and permeability values in a computational table in the simulator. The values of the analytical model and the numerical simulator were presented in a *semi-log* and *log-log plot* and the results matched.

Analytical Model

The NHDE for the oil flow in a permeability pore pressure dependente porous media is:

$$\nabla^2 p - \frac{1}{\eta(p)}\frac{\partial p}{\partial t} = f(\mathbf{r}, t) \quad (1)$$

The new proposed pseudopressure function is:

$$m(p) = \int_{p}^{p_b} k(p')dp' \quad (2)$$

Where: $\eta(p)$ is hydraulic diffusivity function [sec/m^2]; $f(\mathbf{r},t)$ is the oil source [kgf/cm^2], $\mathbf{r}$ is the position vector in Cartesian coordinates (x, y, z) [m], t is the time [sec], p_b is a reference pressure [kgf/cm^2], $k(p')$ is the permeability pore pressure dependent function [mD] and $m(p)$ is the pseudopressure function [$mD\ kgf/cm^2$] .The dimensionless variables are:

$$x_D = \frac{x}{L_c} \quad (3)$$

$$y_D = \frac{y}{L_c} \quad (4)$$

$$t_D = \frac{k_0 t}{\phi \mu c_t L_c^2} \quad (5)$$

$$k_D = \frac{k(p)}{k_0} \quad (6)$$

$$m_D(x_D, y_D, t_D) = \frac{2\pi h \Delta m(p)}{q\mu} \quad (7)$$

Where: $x_D, y_D, t_D, k_D, \eta_D$, and $m_D(t_D)$ are the dimensionless Cartesian coordinates, time, permeability, hydraulic diffusivity function and wellbore pseudopressure, respectively. k_0 is permeability in initial pressure [mD]; η_0 is hydraulic diffusivity in initial pressure, [sec/m^2]; t is time [sec]; c_t is total compressibility, [$cm^2/\ kgf$]; μ is fluid dynamic viscosity [cp] and h is the reservoir thickness [m]. The dimensionless form of the dimensionless NHDE is:

$$\frac{\partial^2 m_D}{\partial {x_D}^2} + \frac{\partial^2 m_D}{\partial {y_D}^2} - \frac{1}{k_D(m_D(x_D, y_D, t_D))}\frac{\partial m_D}{\partial t_D} = -f_D(x_D, y_D, t_D) \quad (8)$$

The general solution is:

$$m_D(x_D, y_D, t_D) = -\frac{1}{2}\boldsymbol{Ei}\left(-\frac{(x_D - L_D)^2 + {y_D}^2}{4t_D}\right) + -\frac{1}{2}\boldsymbol{Ei}\left(-\frac{(x_D + L_D)^2 + {y_D}^2}{4t_D}\right) + \int_0^\infty\int_0^\infty\int_0^{t_D}\left\{\frac{1}{k_D(p_{wD}(t'_D))} - 1\right\}\frac{\partial p_{wD}}{\partial t'_D} \times \frac{1}{4\pi(t_D - t'_D)}\left\{e^{-\left[\frac{(x_D - x'_D)^2 + (y_D - y'_D)^2}{4(t_D - t'_D)}\right]} + e^{-\left[\frac{(x_D + x'_D)^2 + (y_D + y'_D)^2}{4(t_D - t'_D)}\right]}\right\} dt'_D dx'_D dy'_D \quad (9)$$

Results and Discussions

Fig.2 shows the *semi-log plot* of the dimensionless pseudo-pressure as function of the dimensionless time. The smooth displacement between the curves shows the effect of the permeability drop, in comparison to the linear solution p_{wD} . **Fig.3** shows the *log-log plot* of the dimensionless pseudo-pressure and its Bourdet derivative as function of the dimensionless time. The sealing fault effect can be notice through the slope amplification of the derivative curve.

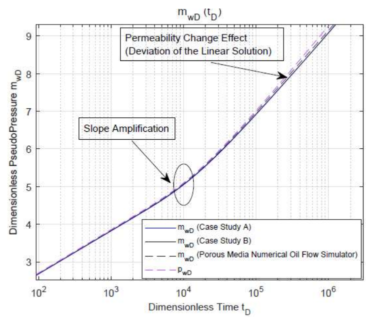

Fig.2: *Semi-log plot* of the dimensionless pseudo-pressure as function of the dimensionless time.

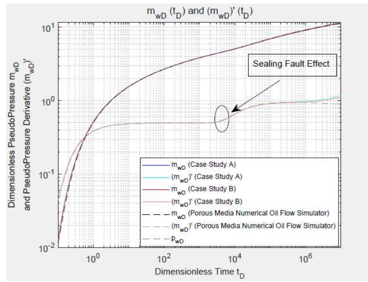

Fig.3*: Log-log plot* of the dimensionless pseudo-pressure and its Bourdet derivative as function of the dimensionless time.

Conclusions

This work presented an analytical solution of the NHDE for permeability decay evaluation along a reservoir life cycle based on coupled GF-integro-differential model. The results were compared to a porous media oil flow simulator and has shown close accuracy , therefore it may be a useful mathematical tool to calibrate new numerical models that may arise in porous media literature.

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