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A Semianalytical Thermal Multiphase Wellbore Flow Model for Use in Reservoir Simulation

S. Livescu, L.J. Durlofsky, and K. Aziz, Stanford University

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Abstract

The detailed interactions between the reservoir and the wellbore are especially important in thermal processes such as steam flooding and in situ upgrading. These linkages must therefore be captured in thermal simulations. Although fully-coupled thermal wellbore-reservoir flow simulators have been developed, the implementation of the thermal well model is somewhat complicated and the simulations are computationally demanding. In this paper, we present a semianalytical treatment that enables a fairly straightforward extension of existing isothermal wellbore flow models to the nonisothermal case. The procedure entails the use of analytical solutions for wellbore temperature applied in conjunction with numerical solutions of the reservoir mass and energy balance equations coupled with wellbore mass and momentum balance equations. The approach thus enables a degree of decoupling between the wellbore flow and energy problems. We proceed by first presenting analytical solutions for wellbore temperature, developed under various assumptions (some of these solutions have been obtained previously). We then describe the use of one of these solutions, which allows for general variation of in situ phase fraction and other properties along the wellbore, within the semianalytical context. The implementation of the overall method into a general purpose research simulator is also described. Results are presented for several cases involving multiphase flow in monobore and multilateral wells. Close agreement with reference solutions, obtained from a fully-coupled thermal wellbore-reservoir model, is demonstrated for all of the examples. The semianalytical treatment is additionally shown to provide comparable or improved computational efficiency relative to the fully-coupled model. The overall procedure is therefore very well suited for use in general thermal reservoir simulation.

Introduction

Thermal recovery processes such as steam flooding and downhole heating are essential for the production of heavy oil and oil sands. Downhole heating is also under investigation for the recovery of oil from oil shales. For any of these processes, accurate and efficient simulation is essential for reservoir management and process optimization. The wellbore model is particularly important as the detailed interaction between the reservoir and wells can substantially impact reservoir performance.

In recent work (Livescu et al., 2008), we developed a fully-coupled, thermal wellbore-reservoir simulator. Detailed coupling is essential because flow from the reservoir into the wellbore (in the case of a production well) provides the source terms for the wellbore flow model, and these source terms depend strongly on reservoir variables. The formulation was implemented into Stanford's General Purpose Research Simulator (GPRS). The general simulator is described in detail by Cao (2002) and Jiang (2007). Within the thermal black-oil context, the wellbore flow model entails the one-dimensional (axial) time-dependent solution of mass conservation equations for oil, water and gas, a momentum balance (or pressure drop) equation, and an energy equation. A drift-flux representation is applied to account for slip between phases (Holmes et al., 1998). The detailed parameters appearing in the drift-flux model were determined from large-scale two and three-phase flow experiments performed over a range of flow rates and pipe inclinations (Oddie et al., 2003; Shi et al., 2005a,b). The thermal wellbore flow model also accounts for heat transfer between the well and the reservoir, temperature-dependent property variation, and transient effects.

The fully-coupled thermal wellbore-reservoir formulation described above is comprehensive and general, though the implementation is quite complex. In addition, the detailed development described in Livescu et al. (2008) is specific to the underlying isothermal wellbore flow model used within GPRS. The goal of this paper is to introduce and evaluate a semianalytical thermal wellbore flow model. This entails the numerical solution of the wellbore flow equations coupled with