Available online at www.sciencedirect.com
ScienceDirect
Mathematics and Computers in Simulation 118 (2015) 273–292
MATHEMATICS AND COMPUTERS IN SIMULATION
www.elsevier.com/locate/matcom

Original articles

Nearwell local space and time refinement in reservoir simulation

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Received 24 March 2014; received in revised form 13 August 2014; accepted 20 November 2014
Available online 10 December 2014

Abstract

In reservoir simulations, nearwell regions usually require finer space and time scales compared with the remaining of the reservoir domain. We present a domain decomposition algorithm for a two phase Darcy flow model coupling nearwell regions locally refined in space and time with a coarser reservoir discretization. The algorithm is based on an optimized Schwarz method using a full overlap at the coarse level. The main advantage of this approach is to apply to fully implicit discretizations of general multiphase flow models and to allow a simple optimization of the interface conditions based on a single phase flow equation.

Keywords: Two phase Darcy flow; Nearwell refinement; Local time stepping; Domain decomposition; Optimized Schwarz methods

1. Introduction

Nearwell regions in reservoir simulations usually require fine space and time scales due to several physical processes such as higher Darcy velocities, the coupling of the stationary well model with the transient reservoir model, high non linearities due to phase appearance (typically gas), complex physics such as formation damage models. In addition the nearwell geological model is usually finer in the nearwell region due to available data.

If Local Grid Refinement (LGR) is commonly used in reservoir simulations in the nearwell regions, current commercial simulators still make use of a single time stepping on the whole reservoir domain. It results that the time step is globally constrained both by the nearwell small refined cells and by the high Darcy velocities and high non linearities in the nearwell region. A Local Time Stepping (LTS) with a small time step in the nearwell regions and a larger time step in the reservoir region is clearly a promising field of investigation in order to save CPU time. It is a difficult topic in the context of reservoir simulation due to the implicit time integration, and to the coupling between a mainly elliptic or parabolic unknown, the pressure, and mainly hyperbolic unknowns, the saturations and compositions.

Different approaches combining LTS and LGR have been studied for reservoir simulation applications. The first class of algorithms belongs to Domain Decomposition Methods (DDM). Matching conditions are defined at the

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http://dx.doi.org/10.1016/j.matcom.2014.11.022

nearwell reservoir interface with possible overlap, and a Schwarz algorithm is used to compute the solution. In the context of LTS, such DDM algorithms were first analysed by Ewing and Lazarov [5] for parabolic problems in terms of stability, error estimates and convergence of the domain decomposition method. Then, Mlacnik and Heinemann [9, 10] have proposed an extension to multiphase Darcy flow reservoir models using a sequential (non iterative) approach. They first compute, on the global LGR grid and with the coarse time step, an approximate solution using a simplified model. Then, the solution is computed on the nearwell region and with the fine time step using Dirichlet boundary conditions given by the previous step at the reservoir nearwell region interface. This approach is improved in [7] using a predictor–corrector strategy. The predictor is the Mlacnik step, and it is followed by Dirichlet Neumann iterations until a convergence criterion on the matching conditions is achieved.

The second class of methods use both the coarse grid on the full domain and the LGR nearwell grid. These grids communicate both at the reservoir nearwell interface and also between the perforated fine and coarse cells (well interface). In the Eclipse simulator [4] a sequential version (usually called windowing) of this approach is implemented with Neumann or Dirichlet boundary conditions at the nearwell reservoir interface and at the well interface.

We propose to combine this latter windowing approach with a DDM Robin–Neumann algorithm coupling the coarse grid solution with full overlap to the refined (in space and time) nearwell grid solution. An efficient iterative algorithm is obtained using at the nearwell reservoir interface optimized Robin conditions for the pressure and Dirichlet conditions for the saturations and compositions. At the well interface, a Neumann condition is imposed for the pressure (assuming to fix ideas that the well condition is a fixed pressure) and input Dirichlet conditions are imposed for saturations and compositions.

The optimization of the Robin coefficients is done on a single phase flow parabolic equation for the reference pressure using existing theory for optimized Schwarz methods (see [8]), while the algorithm is applied on fully implicit discretization of two phase Darcy flows.

This paper is organized as follows. Section 2 describes the construction of our Domain Decomposition algorithm which is presented to fix ideas in the case of a gas injection through a multi-perforated well in a closed reservoir saturated with water. Section 3 assesses the efficiency of our DDM algorithm on two 3D test cases both in terms of accuracy and CPU time compared with the reference solution obtained using the LGR grid with the global fine time stepping. Our Robin–Neumann DDM algorithm is also compared with the classical windowing algorithm [4]. The first test case simulates the injection of gas through a multi-perforated well in a close reservoir saturated with water taking into account the gas dissolution in the liquid phase. The second test case models the production of a gas condensate through a multi-perforated vertical well taking into account the appearance of the oil phase in the nearwell region.

2. Domain decomposition method (DDM) for a two phase Darcy flow model

2.1. Simplified two phase flow model

To simplify the presentation of the DDM algorithms, we will consider in the following the example of an immiscible compressible two phase Darcy flow not taking into account the capillary pressure. The algorithms presented in this section readily extend to more complex models such as multi-phase compositional models with capillary pressure. To fix ideas the model describes the injection of a phase 2 (gas) in a 3D reservoir Ω_r initially saturated with a phase 1 (liquid) through a vertical well. Let us denote by Γ_r the outer boundary of the reservoir (cf Fig. 1) assumed to be impervious, and by Γ_w the inner boundary of the reservoir corresponding to the boundary of the vertical well. The velocities of the phases are given by the two phase Darcy laws

$$\mathbf{V}^{(\alpha)} = -\frac{k_r^{(\alpha)}(s^{(\alpha)})}{\mu^{(\alpha)}}\,\mathbf{K}\,(\nabla p - \rho^{(\alpha)}(p)\mathbf{g}), \quad \alpha = 1, 2,$$

where $\mathbf{g}$ is the gravity vector, p is the pressure, $s^{(\alpha)}, \alpha = 1, 2$ are the phase volume fractions called saturations, $k_r^{(\alpha)}(s^{(\alpha)})$ are the relative permeabilities, and $\mu^{(\alpha)}$, $\alpha = 1, 2$ are the phase viscosities assumed to be constant. Both phases are assumed compressible with mass densities denoted by $\rho^{(\alpha)}(p), \alpha = 1, 2$. The rock permeability is denoted by $\mathbf{K}$ and the rock porosity by ϕ. Then, the pressure p and saturations $s^{(\alpha)}$, $\alpha = 1, 2$ unknowns are solutions of the mass conservation of the gas and liquid phases with phase velocities given by the Darcy laws, coupled to the pore