Workshop on Simulation of Complex Processes in Porous Media

IMPA, Rio de Janeiro, Brazil
September 25-26, 2015

PROGRAM and ABSTRACTS

Organizing Committee:

Jan Martin Nordbotten (University of Bergen/Princeton University)
Martinus Th. van Genuchten (UFRJ/Utrecht University)
Alexei A. Mailybaev (IMPA)

PROGRAM

IMPA, auditorium 232

Friday, September 25

9:30 Registration

09:45 Welcome

10:00 Marcio A. Murad (LNCC, Brazil)
A New Matrix-Fracture Multiscale Coupled Model For Flow in Shale Gas Reservoirs

11:00 Dan Marchesin (IMPA, Brazil)
The role of geochemistry in the recovery of oil in calcite reservoirs by carbon dioxide

Lunch

14:00 Martinus Th. van Genuchten (UFRJ, Brazil / Utrecht University, Netherlands)
An overview of selected collaborative porous media research projects between Brazil and The Netherlands

15:00 Paulo Herrera (Universidad de Chile)
Streamlines numerical simulations of mixing in complex groundwater flow topology

Coffee break

16:30 Antoine Tambue (University of Cape Town, South Africa)
A Rosenbrock-Type Method for simulation of liquid-vapor flows with phase change in geothermal systems

Cocktail

Saturday, September 26

10:00 Alexei A. Mailybaev (IMPA, Brazil)
Liquid-gas filtration combustion in porous media: Theory, simulations and applications

11:00 Juan Nogues (Universidad Paraguayo Alemana)
Influence of the permeability model in the local capillary trapping process

Lunch

14:00 Juan Galvis (Universidad Nacional de Colombia)
A mass conservative generalized multiscale finite element method applied to two-phase flow in heterogeneous porous media

15:00 Renato M. Cotta (UFRJ, Brazil)
Computational Integral Transforms for Heat and Mass Transfer in Porous Media

Coffee break

16:30 Jan Martin Nordbotten (University of Bergen, Norway / Princeton University)
Finite volume methods for coupled flow and deformation in porous media

A New Matrix-Fracture Multiscale Coupled Model For Flow in Shale Gas Reservoirs

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July 21, 2015

Abstract

A new multiscale model for coupled gas flow in hydraulic fractures and multiporosity shale matrix is constructed within the framework of the homogenization procedure in conjunction with a reduction of dimension technique where fractures are treated as (n-1) interfaces ($n = 2, 3$). The model for fracture hydrodynamics is obtained by averaging the mass conservation equation across the fracture aperture giving rise to a reduced balance law posed in the interface supplemented by a source term arising from the jump in the gas flux from the shale matrix. In order to build a model for such matrix flux we construct a new pressure equation for gas hydrodynamics at the mesoscale, where the shale is envisioned an homogenized matrix composed of interparticle pores and nanopores within the kerogen along with an impermeable inorganic matter constituted by a reactive clay and an inert solid phase. Constitutive laws for the retardation parameter which captures the adsorption of methane in the nanopores are constructed from the homogenization of the finer scales. Within the framework of the multiscale model we postulate governing equation at the microscale where kerogen particles and nanopores are viewed as overlaying continua forming the organic aggregates at local thermodynamic equilibrium with the free gas in the water partially saturated interparticle pores and also with adsorbed gas at the surface of inorganic matter occupied by clay. The behavior of sorbed gas lying in the kerogen aggregates and on the clay surface is coupled with both Fickian diffusion of dissolved gas in water and Darcy free gas flow in the interparticle pores. By postulating continuity of fugacity between free and dissolved gas in the interparticle pores and neglecting the water movement, the microscopic problem is upscaled to the mesoscale where kerogen aggregates, inert inorganic matter, clay and interparticle pores are homogenized. The upscaling furnishes a new storage parameter and effective conductivity which appear in the pressure equation dependent on pressure, the total carbon content (TOC), water saturation, clay content and nano and micro porosities. The closure of the fracture/matrix coupled system hinges on the constitutive law for the partition coefficient governing gas adsorption within the intra-kerogen nanopores and on the clay surfaces. Such constitutive laws are derived from the adsorption isotherms rigorously constructed from the Thermodynamics of confined gases seated on the Density Functional Theory (DFT). Numerical simulations illustrate the potential of the multiscale approach proposed herein in computing gas production in different flow regimes.

Key words: Shale Gas Reservoir, Pressure Equation, Homogenization, Density Functional Theory, Hydraulic Fractures, Dimension Reduction, Gas Adsorption

An overview of selected collaborative porous media research projects between Brazil and The Netherlands

Martinus Th. van Genuchten

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Department of Earth Sciences, Utrecht University, Netherlands

This presentation provides a brief overview of various ongoing research projects between Brazil (mostly the Federal University of Rio de Janeiro) and The Netherlands (mostly Utrecht University). Projects from the smaller to the larger scales involve (1) pore-scale imaging and pore network modeling, (2) pore-scale modeling and experimentation of the hydraulic properties of unsaturated media, especially as related to compaction, (3) pore-space evolution of reacting porous media (as related to changes in solute transport properties), (4) detailed measurements and modeling of the dual-porosity nature of water flow and solute transport properties of tropical soils (oxisols), (5) measurement and modeling of soil water hysteresis of unsaturated porous media, (6) upward diffusion of volatile organics from contaminated groundwater through the vadose zone, (7) subsurface drip irrigation in agricultural operations, (8) detailed monitoring and modeling of the water table and estimating recharge of a Brazilian aquifer, (9) multicomponent contaminant transport stemming from the application of vinasse to agricultural fields, and (10) time and spatial averaging of the hydraulic properties of field-scale systems (e.g., as applied to layered surface soils or landfill covers).

Streamlines numerical simulations of mixing in complex groundwater flow topology

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Abstract:

Macroscopic mixing of compounds dissolved in groundwater is due to the combined action of pore-scale dispersion and stretching and folding of the volume occupied by the solute due to Darcy-scale flow variations. Mixing is a key element in practical applications such as in-situ and bio-remediation of contaminated aquifers, and the design of chemicals reactors, among others.

The study of mixing in porous media through numerical simulations is difficult because of numerical dispersion, which produces numerical artifacts that can make difficult to identify the impact of physical dispersion. Such numerical artifacts can be particularly problematic in complex flow fields.

We present results of high resolution 3D numerical simulations performed with a hybrid streamline code, which includes the effect of solute mass exchange between adjacent streamlines and it is free of transverse numerical dispersion. This numerical approach is well suited to investigate potential enhancement of mixing due to stretching and folding in 3D flow fields with complex topology that may arise in presence of anisotropic permeability.

We use the results of the numerical simulations to characterize solute transport in terms of different parameters such as: moments of breakthrough curves, peak concentrations, dilution index, etc; for a range of transverse dispersion coefficients. Based on these results we demonstrate the importance of transverse dispersion in transport processes in complex 3D groundwater flow fields.

A Rosenbrock-Type Method for simulation of liquid-vapor flows with phase change in geothermal systems

A.Tambue, I. Berre J. M. Nordbotten

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Numerical analysis of multidimensional flow and heat transfer in porous media is intrinsically complicated and often prohibitive in terms of computational cost, particularly when phase-change occurs. One of the main reasons is the strongly nonlinear and coupled nature of the governing equations. Another fundamental difficulty lies in the presence of moving and irregular interfaces between the single and two-phase subregions in a domain of interest, which degenerate the mathematical model. This degeneration leads to strict time step restrictions; consequently, efficient and stable time integrators are needed.

In this paper, a Rosenbrock-Type Method for time integration combined with the finite volume method (two-point approximation) space discretizations are used for numerical simulations of liquid-vapor flows with phase change in geothermal systems. As all Rosenbrock-Type methods, this scheme use the rational functions of the Jacobian and only two linear systems are normally solved at each time step, thus no need to solve nonlinear algebraic equations as with standard implicit methods. Furthermore, this scheme is L-stable and the order of convergence is preserved for any relatively good approximation of the Jacobian. We investigate the performance of the method for realistic geothermal model problems and the convergence of the method through numerical examples.

Liquid-gas filtration combustion in porous media: Theory, simulations and applications

M. A. Endo Kokubun, F. P. Santos, D. Marchesin, A. A. Mailybaev (IMPA, Brazil)
N. Khoshnevis Gargar, H. Bruinning (TU Delft, The Netherlands)

We review the results on the in situ combustion of light (low viscosity) oil modeled as one or multi-component liquid. This problem originates from the Enhanced Oil Recovery method by air injection, and its mathematical model describes two-phase multi-component flow in porous medium with reaction and phase transition source terms. The problem is challenging for numerical simulations due to small scales introduced by reaction and phase transitions. Also, it features the fundamentally different combustion mechanism compared to the well-understood in situ combustion of heavy (large viscosity) oils. We review various results of numerical simulations, recent theoretical developments and discuss some open problems and applications.

Influence of the permeability model in the local capillary trapping process.

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Abstract

For many years, the heterogeneity in the capillary pressure have been neglected in several simulators and computational codes. Saadatpoor et al. (2009) have demonstrated that the inclusion of the capillary pressure heterogeneity effects in the buoyancy-driven CO_2 plumes within deep aquifers result in a strong barrier to the non-wetting phase. After a short time, this phenomena was proposed it as a new trapping mechanism (Saadatpoor et al., 2010). In our work, the capillary pressure heterogeneity is generated by constructing an heterogeneous entry pressure field with the Leverett-J function, (Leverett et al., 1941). Inhere, we focus on the effect of the permeability field in the local-capillary trapping process. Moreover, we consider three different models proposed by Zinn (2003), the first model has connected high-conductivity structures, the second has connected structures of intermediate value; and the third has connected regions of low conductivity. In order to determine which are the differences among these models, we perform several numerical simulations and measure the leaked volume of CO_2 that pass through an horizontal high permeability barrier. The results show that, the inclusion of capillary heterogeneity have a strong influence in the flow of CO_2 (or leaked volume), and the different models only affect in small proportion.

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[2] Universidad Nacional de Asunción - Facultad Politécnica

References

Leverett, M. et al. (1941). Capillary behavior in porous solids. *Transactions of the AIME*, 142(01):152–169.

Saadatpoor, E., Bryant, S. L., and Sepehrnoori, K. (2009). Effect of capillary heterogeneity on buoyant plumes: A new local trapping mechanism. *Energy Procedia*, 1(1):3299–3306.

Saadatpoor, E., Bryant, S. L., and Sepehrnoori, K. (2010). New trapping mechanism in carbon sequestration. *Transport in Porous Media*, 82(1):3–17.

Zinn, B. (2003). When good statistical models of aquifer heterogeneity go bad: A comparison of flow, dispersion, and mass transfer in connected and multivariate Gaussian hydraulic conductivity fields. *Water Resources Research*, 39(3):1–19.

A mass conservative generalized multiscale finite element method applied to two-phase flow in heterogeneous porous media

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We propose a method for the construction of locally conservative flux fields through a variation of the Generalized Multiscale Finite Element Method (GMsFEM). The flux values are obtained through the use of a Ritz formulation in which we augment the resulting linear system of the continuous Galerkin (CG) formulation in the higher-order GMsFEM approximation space. In particular, we impose the finite volume-based restrictions through incorporating a scalar Lagrange multiplier for each mass conservation constraint. To test the performance of the method we consider equations with heterogeneous permeability coefficients that have high-variation and discontinuities, and couple the resulting fluxes to a two-phase flow model. The increase in accuracy associated with the computation of the GMsFEM pressure solutions is inherited by the flux fields and saturation solutions, and it is closely correlated to the size of the reduced-order systems. In particular, the addition of more basis functions to the enriched multiscale space produces solutions that more accurately capture the behavior of the fine scale model and still satisfy the conservation restrictions.
This is a joint work with Michael Presho from UT Austin.

Computational Integral Transforms for Heat and Mass Transfer in Porous Media

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The Generalized Integral Transform Technique (GITT) is reviewed as a hybrid numerical-analytical computational tool for the analysis of transport phenomena in porous media. First, the formal solution of a fairly general nonlinear convection-diffusion system is presented, including the treatment of the associated eigenvalue problems through the GITT itself, which form the basis of the proposed eigenfunction expansions. Then, the so called single domain reformulation is discussed, which allows for a more straightforward application of the methodology in handling complex domains and heterogeneous media. The UNIT (Unified Integral Transforms) algorithm built in the *Mathematica* symbolic-numerical platform, an open source implementation of all the analytical and numerical steps in the GITT, is also briefly presented. Second, some of the benchmark problems in natural convection in cavities and forced convection in channels dealt with through the GITT are illustrated, which have been providing reference results for classical multidimensional test cases, while demonstrating the robustness, accuracy and cost effectiveness of the integral transforms method. Third, a few applications of the GITT methodology in the theoretical-experimental analysis of radioactive waste migration in soils and heat transfer in micro-models of porous media are considered. The selected examples provide an overview of the hybrid approach including the required verification and validation of the constructed direct problem models and simulations, together with the related inverse problem analysis for estimating the unknown transport properties and source terms. Finally, some recent developments on multiscale analysis and nonlinear eigenvalue problems are also presented, as part of the discussion on future perspectives for this class of methods in convection-diffusion.

Finite volume methods for coupled flow and deformation in porous media

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Coupled flow within, and deformation of, porous media is crucial in applications as diverse as biomedical image processing and exploitation of geological resources. Herein, we present a new cell-centered finite volume approach to discretizing these coupled equations. The method is applicable to general grids and material heterogeneities.

We give a brief outline of the convergence proof, as well as numerical experiments illustrating the convergence rates. We conclude by brief examples applications including image processing of the human kidney, dessication of drying soils, and CO2 storage.


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