11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
July 20–25, 2014, Barcelona, Spain

A MULTI-SCALE MODEL OF MULTI-FLUID FLOWS TRANSPORT IN DUAL SATURATED-UNSATURATED HETEROGENEOUS POROUS MEDIA

William C. Radunz[1,2], **Francisco B.S. Oliveira**[3] **and Jefferson L.M.A. Gomes**[2]

[1] Department of Mechanical Engineering, School of Engineering, Federal University of Rio Grande do Sul (UFRGS), Porto Alegre, Rio Grande do Sul, 90050-170, Brazil, williamradunz@gmail.com, http://www.mecanica.ufrgs.br
[2] Environmental and Industrial Fluid Mechanics Group, School of Engineering, University of Aberdeen, Aberdeen, AB24 3UE, UK, jefferson.gomes@abdn.ac.uk, http://www.abdn.ac.uk
[3] Department of Exact and Technological Sciences, State University of Santa Cruz (UESC), Ilheus, Bahia, 45662-900, Brazil, fbrunoso@gmail.com, http://www.uesc.br

Key words: *Porous media, Finite element methods, Control volume, Discontinuous Galerkin, Multi-fluid flows, Multi-physics methods.*

Current generation of fluid flow models for porous media flows are very sophisticated, however they are often based on outdated computational methods (e.g. structured or block structured hexahedral FEM- and FDM-based discretisation). Since these methods are often at the heart of transport in porous media, it is vital that these methods are updated in light of recent advances in computational methods and able to exploit the current state-of-the-art mesh-adaptive methods. The latter moves the mesh to follow flow features or interface, and adapts the structure of the mesh to produce optimal anisotropic resolution [1]. The computational effort is thus placed exactly where it is needed.

This paper introduces a conservative computational multi-fluid porous media flows model able to exploit the latest mesh adaptivity methods on fully-unstructured tetrahedral grids. The model is based upon two key numerical characteristics: (a) novel family of P_nDG-P_{n+1} finite element pairs [2] and (b) a consistent overlapping control volume finite element method (CVFEM) formulation. In particular, the P_1DG-P_2 element (i.e., discontinuous and piecewise linear representation for velocity whilst continuous and piecewise quadratic shape functions are used to represent the pressure field) is introduced as the basis of the discretisation and also as the CVFEM counterpart. This is necessary, as it is very difficult to use finite element representation of scalar fields (e.g., saturation and density) and simultaneously ensure physical realism in these solution variables (i.e., positivity and suppression of numerical oscillations provided by high-order or limiting methods).

The main objective of this manuscript is to report the latest development of a generic FEM-based unstructured and adaptive-mesh multi-fluid and multi-component model that can be applied to both inertia-dominated and porous media flows. In the simulations performed in this paper we used P_1DG-P_2 elements and the overlapping CVFEM model [3, 4] where scalar fields (e.g., volume fraction, concentration, density, etc) are represented in the control volume (CV) space and the velocity-pressure dual fields are embedded in FEM space with simultaneous projection into the CV space. High-order accurate downwind schemes on element boundaries on discontinuous scalar fields are flux-limited (based on NVD approach) to obtain bounded and compressive (capturing the interfaces) solutions.

This manuscript focuses on benchmark simulations of dual saturated-unsaturated flows in heterogeneous porous media [5]. Here, a fluid is injected in a porous matrix (subsurface caisson represented by a set of heterogeneous permeability field volumes) and the resulting fluid content (spatial- and time-dependent) during the drainage is qualitively analysed.

REFERENCES

[1] M.D. Piggott, C.C. Pain, G.J. Gorman, P.W. Power and A.J.H. Goddard. h, r, and hr adaptivity with applications in numerical ocean modelling. *Ocean Modelling*, Vol. **10**, 95-113, 2005.

[2] C.J. Cotter, D.A. Ham, C.C, Pain and S. Reich. LBB stability of a mixed discontinuous/continuous Galerkin finite element pair. *Journal of Computational Physics*, Vol. **228**, 336-348, 2009.

[3] J.L.M.A. Gomes, D. Pavlidis, J.R. Percival, P. Mostaghimi, P. Salinas, X. Zie, C.C. Pain, M.D. Jackson, M. Blunt and A. Muggeridge. The Overlapping Control Volume Finite Element Method for Multiphase Porous Media Flow Modelling – Part I: Formulation. *Computer Methods in Applied Mechanics and Engineering*, Submitted, 2013.

[4] M.D. Jackson, J.L.M.A. Gomes, P. Mostaghimi, J.R. Percival, B.S. Tollit, D. Pavlidis, C.C. Pain, A.H. El-Sheikh, A.H. Muggeridge, M.J. Blunt. Reservoir Modelling for Flow Simulation Using Surfaces, Adaptive Unstructured Meshes, and Control-Volume-Finite-Element Methods. *2013 SPE Reservoir Simulation Symposium*, **SPE163633**, 2013.

[5] P.A. Forsyth, Y.S. Wu and K. Pruess. Robust Numerical Methods for Saturated-Unsaturated Flow with Dry Initial Conditions in Heterogeneous Media. *Advances in Water Resources*, Vol. **18**, 25-38, 1995.