Analyse av kontrollvolummetoder - Final report VISTA 2011

by Annette Stephansen — last modified 2011-07-26 09:27

History

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Analyse av kontrollvolummetoder

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Project description

In oil field simulations the flow is often described by a modified Darcy equation. In its original form the Darcy equation described water flowing through tightly packed sand (the so-called porous media) and stated that the flow rate is proportional to the difference in pressure and height. The proportionality constant is called the permeability, which is a property of the porous media and varies when the porous media is not homogeneous. The permeability may favor certain flow directions more than others, in which case we say that the permeability is anisotropic. In most cases the equation cannot be solved analytically, and we define a grid over which faces we wish to obtain an approximate flow field. When discretizing (approximating) the equation the grid may or may not be aligned with the preferential flow directions induced by the permeability. The latter possibility can cause difficulties for certain discretization methods.

The main goal of this project has been to prove the convergence of the MPFA (multi-point flux approximation) methods. The MPFA methods are discretization methods that were explicitly designed to be able to work with grids that are not aligned with the anisotropy of the permeability. To say that a method converges is to say that when the grid size diminishes the quality of the solution is improved. Often we wish to know how well the method converges, that is: if the grid size is diminished by a factor of two, will the solution be twice as good (h-convergence) or perhaps four times as good (h^2 convergence)? From numerical tests we already knew that the MPFA method does not converge on all types of grids and with all types of permeability anisotropies. Also, different MPFA methods give different convergence results. The analysis previously available could tell us what the conditions for convergence were on triangles and quadrilaterals for the MPFA O-method. The difficulty was to extend this analysis to more general grids in 2D and 3D. No analysis was available for the MPFA L-method.

Numerical testing can give us a feeling for how well a method behaves, but analysis is also important. The convergence analysis gives us a tool to decide which method to be used under which circumstances and to better understand the strengths and the weaknesses of different discretization methods.

Results

At the end of the project convergence has been proved for both the MPFA O-method and L-method on general grids in 3D. The analysis is based on an assumption that gives a requirement regarding the grid and the anisotropy. The analysis gives insight as to why the MPFA O-method and L-method give different convergence results depending on the grid and also establishes a close link between the MPFA methods and a group of methods known as the mimetic finite difference method. The goal of the project has thus been obtained. Inspired by the usage of the MPFA method on polygons we have also investigated an interpolation that can be used to trace streamlines from the fluxes given by the MPFA method. While the MPFA method provides a discretization for one-phase flow that is easily updated to two-phase flow when the relative permeability is a scalar, we have also looked at how MPFA-like discretizations may be done when the relative permeability is a matrix. A similar investigation has also been done by Statoil based on the two-point flux approximation method.

Publications

Proceedings:

Stephansen, Annette F.; Keilegavlen, Eirik; Nordbotten, Jan M.;

Simulating two-phase flow in porous media with anisotropic relative permeabilities
Proceedings of SPE Reservoir Simulation Symposium 2011, SPE 141552

Klausen, Runhild A.; Stephansen, Annette F.;
Convergence and reproduction of uniform flow
12th European Conference on the Mathematics of Oil Recovery (ECMOR XII), Oxford, UK, 2010

Stephansen, Annette F.;
Convergence of the MPFA L-method - Strengths and Difficulties
12th European Conference on the Mathematics of Oil Recovery (ECMOR XII), Oxford, UK, 2010

Stephansen, Annette F.; Klausen, Runhild A.;
Mimetic MPFA
11th European Conference on the Mathematics of Oil Recovery (ECMOR XI), European Association of Geoscientists and Engineers ISBN 978-90-73781-55-9 2008

Accepted articles:

Klausen, Runhild A.; Stephansen Annette F.;

Convergence of multi-point flux approximations on general

grids and media

Accepted for publication in International Journal of Numerical Analysis and Modeling

Keilegavlen, Eirik; Nordbotten, Jan M.; Stephansen, Annette F.;
Tensor Relative Permeabilities: Origins, Modeling and Numerical Discretization
Accepted for publication in International Journal of Numerical Analysis and Modeling

Submitted articles:

Stephansen, Annette F.;

Convergence of the MPFA L-method on general grids

Klausen, Runhild A.; Rasmussen, Atgeirr; Stephansen, Annette F.;

Velocity interpolation and streamline tracing on irregular geometries

Possibilities for future research

There are some interesting directions which one could pursue following the results of this project. First of all, the analysis has been done for two different MPFA methods; it would be interesting to investigate how to use the flexibility of the MPFA methods all in one scheme. The goal would then be to optimize the choice of MPFA method locally based on criteria like convergence and monotonicity, but also just feasibility if the grid is particularly deformed.

Regarding monotonicity, the criteria needed in 2D to be able to avoid oscillations are known. However, the analysis has not been extended to 3D, which therefore would make an interesting topic for further research.

Another option would be to analyze the behavior of the MPFA methods when used as multi-scale methods. While the MPFA method has been implemented in different ways in order to obtain the fine-scale solution, further analysis could help to indicate how to best capture the fine-scale solution and to uncover possible pit-falls.