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BLACK OIL RESERVOIR SIMULATION USING MONOTONE NON-LINEAR FINITE VOLUME METHOD ON POLYHEDRAL MESHES

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Reservoir simulation applications can use different types of meshes such as tetrahedral, hexahedral, prismatic, PEBI, etc. These meshes fall in the class of conformal meshes with polyhedral cells. Numerical geologic models of hydrocarbon reservoirs continue to grow in complexity creating a demand from the reservoir simulation community for simple and accurate conservative numerical methods applicable to general conformal meshes and anisotropic permeability tensor coefficients.

Discretizations using conservative approximation techniques applicable to reservoir simulation are well known: cell-centered finite volume (FV), multipoint flux approximation (MPFA), mixed finite element (MFE), and mimetic finite difference (MFD) methods. The first method (FV) with a linear two-point flux approximation (TPFA) is monotone and second-order accurate in case of isotropic properties on orthogonal grids but loses its accuracy for anisotropic problems or unstructured grids. The last three methods (MPFA, MFE, MFD) are second-order accurate but are not monotone in case of unstructured grids or anisotropic permeability fields. Most reservoir simulators use the finite volume method to model flows in porous media due to technological simplicity and useful properties of consistency and monotonicity.

In this presentation we consider a new cell-centered finite volume method that preserves solution positivity and consistency. The approach belongs to the class of methods with nonlinear flux approximation [1, 2, 3]. The method is applicable to problems with anisotropic heterogeneous permeability tensor on generic conformal polyhedral meshes [3]. The approximation of advective fluxes is based on the upwinding approach along with a piecewise linear reconstruction of the FV solution and a slope limiting technique. The method implemented in the research reservoir simulator is exact for linear and piecewise linear solutions and thus has the second order truncation error.

The new nonlinear two-point flux discretization (nTPFA) has a number of important advantages over traditional linear two-point flux approximation scheme. The first, it demonstrates very low sensitivity to grid distortion. The second, it provides appropriate approximations in the case of full anisotropic permeability (diffusion) tensor. The third, being combined with the cell-centered finite volume method, it preserves solution positivity and thus provides a monotone discretization.

The new technique has also practical advantage over other high-accuracy methods like MPFA, MFE, or MFD. As it requires the same topology of connections between degrees of freedom as a standard linear TPFA method, its implementation fits well into infrastructure of existing reservoir simulators based on cell-centered FV method. The modifications required only in the Jacobian and residual computations as well as in some parts of the code responsible for non-linear iterations.

We apply the new FV method using nTPFA for modeling water flooding problem using black oil formulation. The two-phase flow of immiscible fluids is simulated using fully implicit method. It is shown that the quality of the discrete flux in a reservoir simulator has a great effect on the front behavior and the water breakthrough time in the presence of distorted grids and non-isotropic transport properties.

We compare solutions computed using two methods for the flux approximation: the conventional linear TPFA and the new nTPFA. It is experimentally confirmed that in special case of orthogonal grid with isotropic or grid-aligned anisotropic permeability tensor (so-called K-orthogonal grid) MPFA, linear TPFA and nTPFA provide identical solutions. On the other hand, if the grid is not K-orthogonal, the linear TPFA provides no approximation of the flux, while nTPFA is still at least first-order accurate and preserves the sparsity of the linear TPFA, in contrast to MPFA. Numerical experiments practically demonstrate significant loss of accuracy due to the conventional TPFA and thus justify the use of the nonlinear TPFA alternative.

Along with the experimental comparison of accuracy, we analyze the performance of both methods implemented in a black oil reservoir simulator. Experimental results reveal that although the application of nTPFA is more expensive than the use of conventional TPFA approach, the increase of computational cost is acceptable for practical industrial application. The most of the additional computational cost is concentrated in the Jacobian calculation and the linear solver.

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