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REPRESENTING DEPENDENT VARIABLE DISCONTINUITIES IN HYBRID FINITE-ELEMENT FINITE-VOLUME MODELS OF HYDROCARBON RESERVOIRS: COMPARISONS BETWEEN ELEMENT-CENTERED WITH MULTIPLICATED NODE METHOD FOR UNSTRUCTURED GRIDS

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Hybrid finite element – finite volume methods are well suited for the solution of multi-physics problems on complex model geometries, for example, capillary-, gravity- and pressure-gradient driven multiphase flow through fractured porous media [e.g., 1]. The complementary advantageous features of these two integral schemes find simultaneous application through operator splitting, using the FEM to solve the elliptic – parabolic parts of the governing equations (fluid pressure, temperature and chemical diffusion, geomechanics) and the FVM to solve the hyperbolic ones (multi-component / saturation and concentration transport). Material domains with jump discontinuities are discretized with parametric finite elements and consistent finite volume stencils centered on the finite element nodes. This paper evaluates pros and cons of new incarnations of such hybrid schemes with a spatial treatment of material interfaces for the purpose of reservoir simulation on unstructured grids.

In hybrid FE-FV methods different placements of the dependent variables are possible (Fig. 1): Thus, "parabolic" pressure and "hyperbolic" saturation can be placed either on the finite-element nodes and corresponding node-centered finite volumes – or – pressure is placed on the nodes while saturation is placed on the finite elements. In this second method, referred to hereafter as FECFVM, the finite elements are simultaneously used as control volumes. This becomes possible when an extra set of equations is solved to obtain conservative inter-element fluxes [2]. In the FECFVM, permeability, porosity, saturation functions, and saturation all are discretized on the elements. Hence, capillary pressure-induced inter-material saturation discontinuities arise naturally. As unstructured grids contain many more elements than nodes, a correspondingly larger number of saturation degrees of freedom appear as compared with the node-centered pressure and saturation scheme, hereafter referred to as DFEFVM [3]. This method requires insertion of as many additional nodes at domain interfaces as materials are juxtaposed at these sites. Without these, saturation averages get computed that are not physical meaningful and smearing of saturation occurs at the domain boundaries, blurring the effects of heterogeneities on the flow [3]. Note that, by contrast with the Control Volume Finite Element Method (CVFE, Fig. 1) or the PEBI-grid discretization, permeability, porosity and the saturation functions in the DFEFVM all are piecewise constant on the elements. This is decisive for avoiding smeared material interfaces and associated complications like the invocation of transmissibility multipliers.

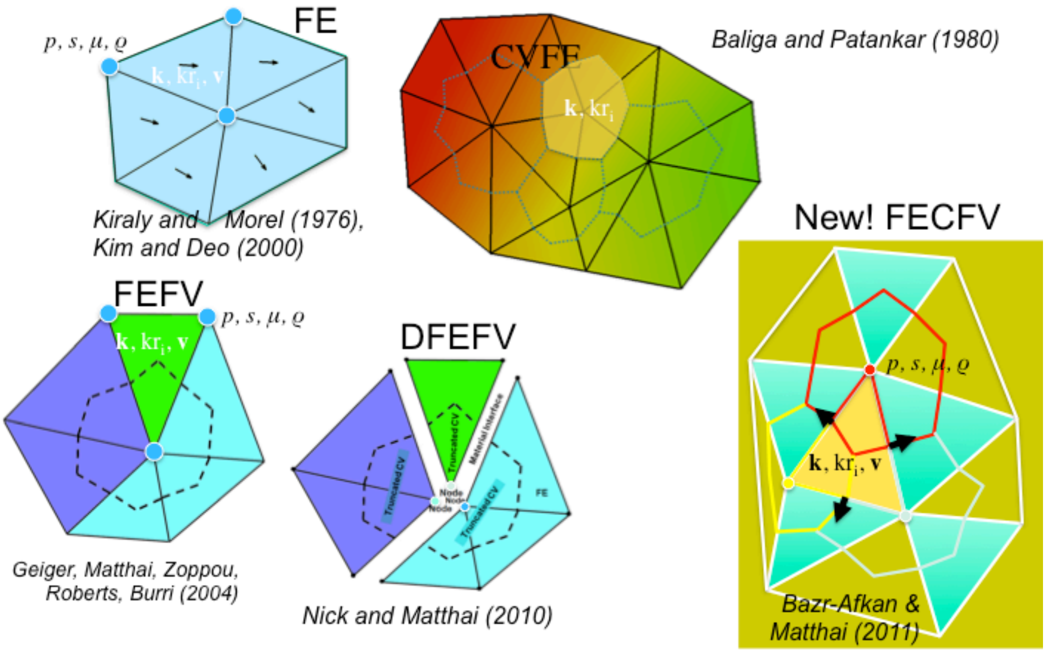

Figure 1: History of hybrid FE-FV discretization schemes. Only DFEFV and FECFV are rigorously applicable to the solution of coupled pressure - multiphase fluid flow equations in the presence of sharp material interfaces; for cited references, see [2].

Cons: the DFEFVM requires more effort from a discretization point of view, and the FECFVM is more expensive from a computational point of view due to the extra set of equations that needs to be solved in each transport step.

Pros: both schemes are less expensive than the Discontinuous Galerkin method. The FECFVM is more compact than the DFEFCVM and its piecewise constant material-conforming saturation variations resemble what reservoir engineers are used to from conventional FD simulators. The DFEFVM is more flexible: cell-based saturation gradients allow a more accurate computation of interface fluxes and capillary effects on global pressure can be considered because it can be discontinuous.

REFERENCES

[1] Matthäi, S.K., Mezentsev, A., and Belayneh, M., Finite-Element Node-Centered Finite-Volume experiments with fractured rock represented by unstructured hybrid element meshes. *SPE Reservoir Evaluation & Engineering,* Vol. **10**, No. 6, pp. 740-756, 2007.

[2] Bazrafkan, S. and Matthai, S. K., A new hybrid simulation method for multiphase flow on unstructured grids with discrete representations of material interfaces. *IAMG conference publication,* 12p., doi:10.5242/iamg.2011.0120, Salzburg, Sept. 5-9th, 2011.

[3] Nick, H. M. and Matthai, S. K., Comparison of three FE-FV numerical schemes for single- and two-phase flow simulation of fractured porous media. *TIPM*, DOI 10.1007/s11242-011-9793-y.