A Hybrid (FEM - Node-Centered FVM) Method with Special Treatment of Wells and Material Discontinuitues for Fast and Spatially Adaptive Simulation of Coupled Reservoir Processes

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Abstract

We present new instruments for solving the "best site selection" problem in a sequential setting, and we propose a comparison with classical non-sequential methods based on the Value of Information. The main motivation is selection of drilling sites in an oil and gas field, when there are several correlated prospects. We discuss the properties and the methods required for designing our optimal sequential program, and we present results on two case studies. Spatial statistics models are used to encode the geological spatial dependence among the sites.

1 Introduction

Ultimate recovery shows a strong inverse correlation with the geological complexity and heterogeneity of conventional hydrocarbon reservoirs. Unfortunately, complex reservoirs, including naturally fractured ones, are the most difficult to represent, mesh/grid, history match and forecast. This makes it hard to optimize production.

2 Method description

This paper describes and benchmarks an alternative new hybrid reservoir simulator for unstructured spatially refined reservoir grids including discrete representations of well completions, inclined faults, and thin reservoir layers with unique flow properties. Apart from its ability to simulate mass-conservative transport on such grids, this simulator's combined use of linear finite elements and node-centered finite volumes, has further advantages when compared with widely used IFD or finite-volume only methods: computation of flow velocities with the finite-element method (FEM) does not rely on the calculation of transmissibility multipliers. For material interfaces this eliminates the associated averaging of flow properties so that natural discontinuities gain a more realistically sharp model representation. It does however require that result variables such as saturation or concentration that are discretized on FE node-centered finite volumes, are enriched by additional degrees of freedom to express potentially discontinuous variations across material interfaces. For this purpose, interface finite volumes are split and resulting isolated material domains are coupled with suitable boundary conditions. Continuity of viscous and gravitational interface fluxes is achieved by p-refinement of finite elements located at these interfaces. This is similar to the discontinuous Galerkin approach (DGM), but has the advantage over the DGM, that the p-refinement and the additional associated degrees of freedom are restricted to material interfaces, reducing computational effort. Wells are represented either by bar-shaped finite elements or by highly refined volumetric meshes with a triangular cross-section. It will be shown that this well discretisation gives the most accurate bottom hole well flowing pressures.

The overall simulation framework permits simulation of Thermal, Hydrologic (multiphase flow), Mechanical and Chemical (THMC) processes and combinations thereof. Resulting systems of linear algebraic equations are solved implicitly with an Algebraic Multigrid Method for Systems (SAMG).

3 Application

We benchmark our hybrid method against a standard commercial IFD simulator for an injector-producer water flood simulation with a sand-shale reservoir geometry including pinch and swell structures and two vertical well completions. For the conventional simulator, this geometry had to be simplified to be able to build the simulation grid. Importantly, since the commercial simulator uses an analytic well model and is based on transmissibility multipliers, smearing the sand-shale contacts, its internal representation of the model differs from that in our hybrid model. The IFD model also has substantially less degrees of freedom than our hybrid model.

4 Results

Results were computed for a water-oil viscosity contrast of 10 and viscous and gravity dominated runs including capillary forces. Compared were flow velocity distributions, patterns of sweep and recovery curves. Prior to the sand-shale flow geometry runs, code components were verified by comparison with standard analytical solutions for pressure diffusion, steady-state bottomhole fluid pressure, Buckley-Leverett displacement theory, and solute advection.

5 Observations

The verified hybrid simulator produces results that are markedly different from those of commercial IFD simulators: The spectrum of flow velocities is wider, instabilities expected for the prescribed mobility ratio show, but are suppressed in the IFD runs. Also, recovery is lower and breakthrough of injected water occurs earlier and is more abrupt than for the IFD simulator. In the hybrid model, simulation speed varies depending on the viscous-gravitational force balance and the time-stepping criteria prescribed. For serial versions of the tested simulators an order-of magnitude speedup relative to the commercial simulator was possible with the hybrid one.

6 Conclusions

This paper presents a new reservoir simulator for unstructured finite-element node-centered finite volume meshes with additional degrees of freedom at material boundaries and discrete representations of well completions. The underlying h-p finite element method is linear except for the material interfaces and is used to solve the elliptic-parabolic equations arising from the conceptual model of the reservoir. Hyperbolic equations are solved with the finite volume method. Discontinuities are realized by effectively "exploding" the mesh along material interfaces and reconnecting equations across discontinuities by means of Neumann and other more complex boundary conditions. A sand-shale waterflood benchmark involving a commercial IFD simulator, gives results markedly different, but deviations can be rationalized in terms of a more realistic representation of the constituent physics by the hybrid simulator.

7 Significance of Subject Matter

Complex reservoirs including naturally fractured ones are the most difficult to represent, mesh/grid, history match and forecast. This makes it hard to optimize their production. Through a more accurate representation of reservoir geometry, material interfaces and the physics of the flow, the new simulator improves our ability to forecast the behaviour of structurally complex heterogeneous reservoirs.