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Localized Solution Methods for the Efficient High-Resolution Simulation of Multiple MFHWs in Unconventional Reservoirs

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Flexible grids with local grid refinement can be used to model multistage fractured horizontal wells (MFHWs). To resolve multiple horizontal wells accurately, an ultrahigh mesh size is often required. Moreover the unstructured mesh and permeability contrast result in very expensive linear solution processes. It was observed however that most Newton update entries resulting from these systems are zero. The objective is to devise and apply a local linear system solution procedure that exploits sparsity and delivers fully implicit solution an order magnitude faster. The method is demonstrated for ultra-high-resolution simulation of water-gas-oil using unstructured triangular meshes with multiple MFHWs in unconventional reservoirs.

In the solution of implicit reservoir simulation time-steps, the Newton iteration updates are often very sparse; this sparsity can be as high as 95% and can vary dramatically from one iteration to the next. We develop a mathematically sound framework to predict this sparsity pattern before the system is solved. The development first mathematically relates the Newton update in functional space to that of the discrete system. Next, the Newton update formula in functional space is homogenized and solved in such a way that it results in conservative estimates of the numerical Newton update. The cost of evaluating the estimates is linear in the number of nonzero components. The estimates are used to label the components of the solution vector that will be nonzero, and the corresponding submatrix is solved. The computed result is guaranteed to be identical to the one obtained by solving the entire system.

When applied to various simulations of three-phase recovery processes in various synthetic unconventional models, the observed reduction in computational effort ranges between four to tenfold depending on the level of total compressibility in the system and on the time step size. When applied to general fully-implicit flow and multicomponent transport, we observe 10-15 fold reductions in simulation time. We apply the solution strategy to allow us to fully resolve multiple hydraulic fractures in the simulation of three phase flow in an unconventional reservoir on a desktop.

This work (1) characterizes the locality/sparsity of general implicit reservoir simulation Newton updates mathematically, and (2) develops a linear solution methodology that focuses computation ideally onto the components that matter. The method will enable efficient and robust full-resolution fully implicit simulation without the errors introduced by adaptive discretization methods or the stability concerns of semi-implicit approaches.

References

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