Industrial Compositional Streamline Simulation for Efficient and Accurate Prediction of Gas Injection and WAG Processes

DE-FC26-04NT15530

Goal

The goal of this project is to show that compositional streamline simulation (CSLS) has very high potential for the simulation of (near) miscible gas injection processes. In this project, researchers are extending and improving a novel and fully adaptive compositional streamline simulator CSLS to three-phase flows. The goal is to increase its computational efficiency so that it will be suitable for use in industry and laboratories for the study of realistic reservoir and production scenarios for a wide variety of gas injection and CO_2 sequestration projects. The simulator development is supported by an experimental program designed to improve understanding of three-phase flows, which could lead to improved mathematical models for three-phase relative permeability functions.

Performer

Stanford University
Stanford, CA

Results

Researchers developed:

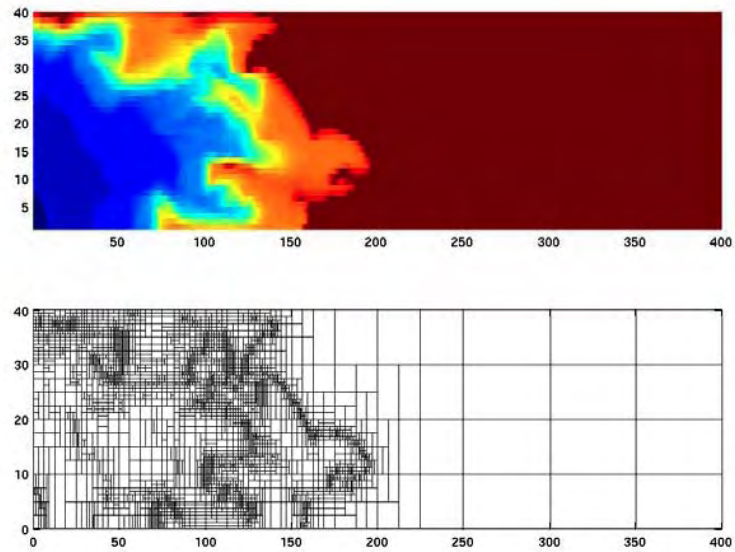
• A novel and accurate pressure solver on Cartesian Cell-based Anisotropically Refined (CCAR) grids. The adaptivity allows refinement in important flow zones, which greatly improves the flow accuracy.

• A novel multi-level permeability and transmissibility upscaling strategy for CCAR grids that significantly reduces the process dependency of the flow solver. This strategy is applicable to other grid refinement strategies.

• A relaxation method for the accurate solution of multi-phase, multi-component flows. Preliminary results show this new method may resolve numerical difficulties associated with the strong nonlinearities inherent in these problems.

Benefits

The CSLS has a high potential for use in quick and reliable assessments of performance and development of management strategies for a wide range of reservoirs involving multi-phase flows. The high-resolution capabilities of CSLS will contribute to a better understanding of the physical processes of multi-phase, multi-component flow in porous media.



AMR is used to construct a grid that is dynamically refined near solution fronts as they advance, as shown in this gas injection problem with an injector in the lower left corner.

CSLS will provide fast and accurate performance predictions of oil and gas reservoirs. It is particularly suited for coupling to optimization algorithms for well placement, surface facilities locations, or reservoir management strategies and will enable optimization studies to be performed in realistic timeframes by industry. This is especially important in remote and/or hostile areas where infill drilling may not be an option and production costs are high. Hence, this proposal addresses the Nation's need to increase domestic oil production in an environmentally sound manner.

This research also will contribute significantly to the study of CO_2 sequestration via injection into subsurface formations. Simulations are needed to predict where CO_2 is likely to flow, interpret the volume and spatial distribution of the subsurface contacted by injectant, and optimize continuous injection operations. CSLS is highly suitable for CO_2 sequestration studies because of its ability to handle complex phase behavior and turnaround solutions very efficiently.

Background

When gas displaces oil at a sufficiently high pressure, the local displacement efficiency can be high. Due to reservoir heterogeneity and the low viscosity of gas, however, the injected gas may contact only a small portion of a reservoir as it finds the high-permeability flow paths, thus limiting global sweep efficiency. The process performance of gas injection schemes depends upon balancing local displacement efficiency with global sweep efficiency, and both need to be captured accurately by a performance prediction tool.

This presents three substantial challenges for reservoir simulators, particularly when a compositional model is used to describe the reservoir fluids:

• Because the global sweep depends foremost on the underlying heterogeneity and gravity, realistic, high-resolution reservoir models are required for accurate predictions.

• In modeling the complicated multi-phase, multi-component flows, it is paramount to have a good physical understanding of the interactions between components in the flowing phases.

• The effects of the physical models used on the performance of the numerical models must be studied carefully, and numerical models must be designed to accurately capture the essential physics.

As a result of these requirements, the computational costs of a reliable compositional reservoir simulation are very high, so computational efficiency becomes critical. In addition, since the physics of multi-phase,

multi-component systems is not fully understood, an experimental program that increases this physical understanding is essential.

Summary

To accomplish these goals, the project entails five interconnected subprojects:

• Design and implementation of a fully adaptive gridding strategy with automatic error control. Current streamline methods attempt to distribute streamlines uniformly and require that at least one streamline pass through each cell on the background grid. The resulting high-streamline density is undesirable, as it increases the requirement for flash calculations. Project researchers are implementing a gridding strategy that adapts streamline density dynamically in order to maintain accuracy in critical regions, while using a minimal number of streamlines in less critical regions. They also will allow for partial streamline tracing to allow very local increases in streamline density, if desirable. Thus far, researchers have incorporated Adaptive Mesh Refinement (AMR) into the pressure solve in order to further improve the efficiency of CSLS and complement the researchers' adaptive solution strategy along streamlines. This prevents the pressure solve from becoming a computational bottleneck for large, field-scale simulations beyond the capabilities of current compositional simulators.

• Parallelization of the streamline code. The streamline method naturally decouples a three-dimensional flow problem into a number of independent, one-dimensional subproblems. Thus parallel implementation is likely to compare favorably with methods that decompose a domain without regard to the flow pattern. Researchers already have parallelized the pressure solve to increase computational efficiency in those cases where frequent pressure updates are necessary and will develop a parallel streamline algorithm in the next phase of the project.

• Investigation of the effects of fluid compressibility on performance predictions and determination of how these effects are best included into the streamline framework. So far, research on compositional streamline simulation published in the open literature is based on the assumption of incompressible flow for the purpose of evaluating the pressure field and subsequently tracing streamlines. Project performers will rigorously investigate the validity of this assumption and the consequences of applying the incompressible approach on performance prediction.

• Extension to three-phase flows with supporting experimental program. Researchers will extend CSLS to three-phase, multi-component flows to properly account for the presence of water and allow application of CSLS to water-alternating-gas (WAG) processes. This development will be supported by an experimental program designed to help improve the modeling of the physical mechanisms in three-phase flows that govern the displacement efficiency along a streamline. The experimental program is essential because it provides a physical basis for the mathematical and numerical developments.

• Application to realistic industrial problems. This subproblem calls for applying CSLS to a comprehensive suite of test problems, including continuous natural gas and CO_2 injection, WAG, enhanced coalbed methane production, and CO_2 sequestration in depleted reservoirs and deep saline aquifers. The suite of test problems will be used to benchmark CSLS, and results will be compared with those generated by commercial simulators.

Current Status (January 2007)

To this point, researchers have focused primarily on developing the efficient parallel and adaptive pressure solve and associated upscaling strategy. They also have developed an initial streamline adaptivity algorithm. This work has also for the first time described retrograde condensate reservoir phase behavior in porous media. Researchers are extending and improving the current CSLS to predict (near) miscible gas injection processes in heterogeneous reservoirs. The focus this past year was on relaxation methods to solve for transport along streamlines. The equations and programming code describe gas injection more accurately than any other code derived to date. The research on the relaxation along streamlines is now complete. The experimental component has to be conducted. The research areas include laboratory work to confirm the models, grid dependency issues, and porting code to a shared memory on a Sun cluster

Funding

This project was selected under DOE's Oil & Gas Program master solicitation DE-PS26-04NT15450 (focus area: Gas Flooding).

Publications

Semi-annual reports for October 2004 through September 2006 available from DOE.

Younis, R., and Gerritsen, M.G., "Multiscale Process Coupling by Adaptive Fractional-Stepping: An In-Situ Combustion Model," Proceedings of SPE/DOE Symposium on Improved Oil Recovery, 2006, SPE 93458.

Mallison, B.T., Gerritsen, M.G., and Matringe, S.F., "Improved Mappings for Streamline-Based Simulation," *SPE Journal*, Volume 11, Number 3, September 2006, pp. 294-302, SPE 89352.

Jessen, K., and Gerritsen, M.G., "High-Resolution Prediction of Enhanced-Condensate-Recovery Processes," Proceedings of SPE/DOE Symposium on Improved Oil Recovery, 2006, SPE 99619.

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Project End: October 31, 2007

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Performer Contribution: $210,026 (21 percent of total)

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