Parallel, Multigrid Finite element Simulator for Fractured/Faulted and Other Complex Reservoirs Based on CCA

DE-FC26-04NT15531

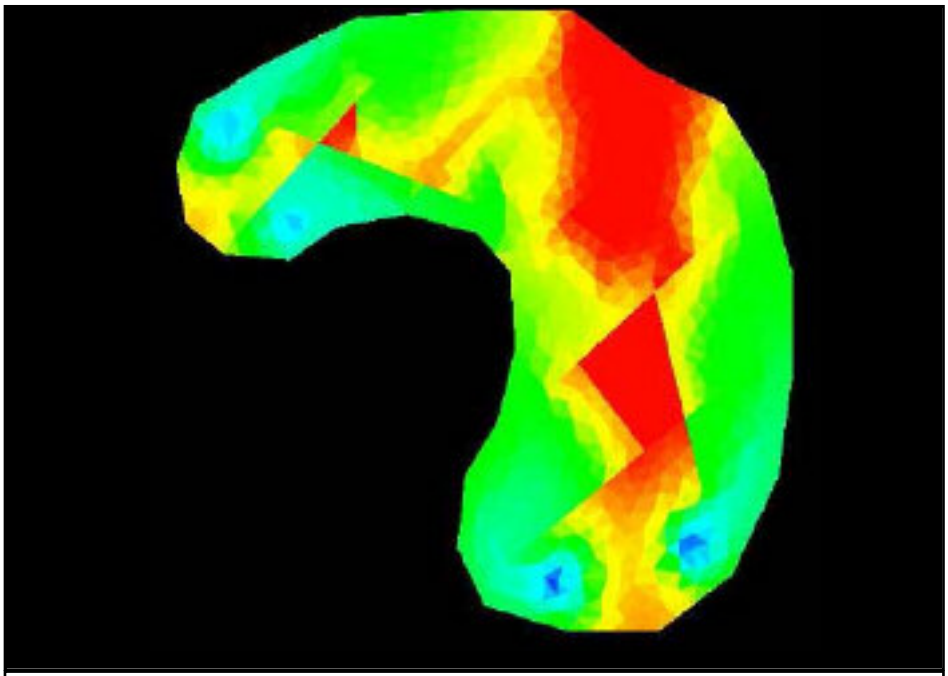
Goal

The objectives of this project are to develop an efficient, general-purpose, finite-element simulator with unstructured grids to model complex reservoirs. Most reservoirs are fractured to a certain degree, and now there are better tools to characterize and map faults and fractures, fieldwide. Generation of reservoir domains with faults and fractures using relevant geological information is one of the tasks. This project would make it possible to incorporate this enhanced characterization directly into a reservoir simulation framework.

One key idea is to develop multi-scale computing schemes so that phenomena at different scales are represented and solved efficiently. This feature will be very important in solving a data set with a number of faults/fractures expeditiously. The goal was also to create a fast simulator with all the modern computational tools. Parallelization of large unstructured grid systems and standardization of files and various components employed are the activities designed to provide the outcome of a parallel, modular simulator of complex systems that is accessible and user-friendly.

This project will:

- Focus on developing a fast finite-element simulator capable of performing compositional and thermal simulations on complex fractured, faulted systems.
- Develop new multiscale methods to model large, fractured systems.
- Create intuitive well models to streamline the representation of simple (vertical, horizontal, or slanted) and complicated (multilateral, maximum reservoir contact) wells.
- Develop a process to map and verify faults and fractures.
- Implement new parallel schemes for dealing with data sets with a large number of fractures.
- Devise a platform to standardize the various components of reservoir simulation using the Common Component Architecture (CCA).



One of the significant achievements in the project thus far is being able to assign flexible conditions to faults and other features. The figure shows a waterflood in a domain with impermeable faults. It is possible now to incorporate discrete features that are fully or partially penetrating or impermeable.

Performer

University of Utah
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Results

The milestone that was scheduled to be met at the end of first year of the project was complete decoupling between the physical models and discretization methods. This has been accomplished. All the tasks are progressing per schedule.

The main goal of this project was to overcome difficulties associated with the representation and simulation of complex fractured/faulted systems with complicated wells. Significant advances were made in achieving this goal with the development of modular simulators that are able to access the most modern computational algorithms. A generic well model to represent complex wells was developed and parallel computing scheme to decompose unstructured-grids with complex wells was devised. A methodology to create three-dimensional unstructured grids of fractured/faulted domains was identified. First steps in the development of compositional and thermal finite-element models were taken. This will lead to the capability of simulating different physical processes (for example, primary production and water flooding followed by CO_2 or steam flooding). A number of technology transfer activities were carried out to disseminate the ongoing research efforts. A close integration of the efforts of geoscientists and engineers made it possible to create simulations of geologically realistic domains.

Benefits

This project will create the first reservoir simulator that is based on fully unstructured grids. Fully unstructured grids are essential in representing complex geometries and wells, which would provide the ability to simulate complex faulted/fractured and non-fractured domains and multilateral and maximum reservoir contact wells. Development of compositional and thermal modules will help study these processes using finite-element grid geometries on a single modular platform over the life of the reservoir. This will make it possible to make reservoir development decisions at the early stages of development.

Work also will begin on the development of an architecture that would allow simple integration of different components making up an effective parallel reservoir simulator. Seamless parallel computing proto-

cols will be developed, to enable implementation of the code on parallel machines.

This project will create tools to better manage fractured/faulted reservoirs and reservoirs with complex wells. Better management of these reservoirs will lead to significant improvement in oil and gas production from these reservoirs.

Background

Most modern reservoir simulators are based on the finite-difference method. This method of discretization is not suitable for representing reservoirs with complex geometry, particularly faulted and fractured systems. Nor is the technique suitable for modeling complex well geometries. Unstructured, finite-element discretization is common in modeling and simulation of medical and aerospace applications. Three-dimensional, three-phase black oil finite-element simulators have been developed at the University of Utah. These provide true unstructured three-dimensional gridding to model complex domains. This project builds on this experience by adding physical processes, well models, parallel schemes, and standardization.

Summary

Integration of geologic information and reservoir engineering evidenced in this project is achieved with a team of geoscientists and engineers.

Significant accomplishments in the current year include:

- A methodology to grid complex, three-dimensional objects with faults and fractures was identified. The approach is to use CUBIT, the general gridding program created at Sandia National Laboratory. Using this tool and the scripts written at the University of Utah, it is now possible to take complicated faulted/fractured domains and create grids to honor the complicated geometry.

- Three-dimensional, three-phase simulations were performed on grids generated using CUBIT. Methods to perform these computations with or without the matrix (fracture only) simulations were developed.

- Multiple ways of creating field-wide fracture networks were identified. Simulations on domain with a complicated set, generated using Fracman (software developed by Golder Inc.), are underway.

- A thermodynamics simulator (obtaining compositions of vapor and liquid phases) using the successive substitution method was completed. This is the first step toward the development of a compositional simulator for fractured/faulted systems.

- Formulation of thermal simulation equations was completed.

- Intuitive well models of complicated wells for the mixed finite-element simulator were developed.

- The simulator structure was modified to use not only the conventional reservoir simulation boundary conditions (bottom hole pressure and rate constraints) but also constant flux boundary conditions and Dirichlet (constant pressure) specifications.

- In order to facilitate the modularization and standardization of simulator components decoupling of the discretization method and the numerical model was performed. The input file was standardized to use the universal XML format.

- Paralleization has been built into the structure of the simulator.

- Seamless coupling with PetSc was accomplished leading to the use of the most advanced linear solvers such as GMRES and TFQMR.

Current Status (January 2006)

These are the tasks for the second year of the project:

- Task 1: Simulator development. Major efforts will be directed toward completion of compositional and thermal simulators. Modules of different types of reservoir simulators with different discretization methods (mixed finite element, control-volume finite element) will be streamlined.

- Task 2: Multiscale methods. The conceptualized multiscale algorithms will be coded. The explicit option will be compared with computation without the multiscale feature. Results will be validated using rigorous boundary conditions on discontinuous features.

- Task 3: Well models. The well models developed will be tested on a variety of wells in different environments. Well models for other discretization methods and physical models will be implemented.

- Task 4: Generation of fracture domains. Realistic fracture domains will be generated using a variety of tools. Ensuring compatibility of the fracture networks with geologic data will be one of the main goals of this task.

- Task 5: Parallel methods. Scalability of the parallel algorithms developed during the first year will be determined on the 18-processor Linux cluster and on larger clusters at the University. Effectiveness of the parallelization schemes for fractured domains and in domains with complicated wells will be examined. ParMetis was the tool of choice for parallelization in the first phase of the project. As dynamic parallelization techniques are explored, use of Zoltan will be considered.

- Task 6: Developing a CCA compliant architecture. The first phase of standardization, with CCA header files in the standard modules already created, will be completed. Use of different physical models with the same discretization method and vice-versa also will be demonstrated.

Funding

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