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HIGH PERFORMANCE COMPUTING IN PETROLEUM APPLICATIONS

RICHARD E. EWING, GUAN QIN AND WEI ZHAO

Abstract. The purpose of mathematical reservoir simulation models in petroleum applications is to try to optimize the recovery of hydrocarbon from permeable underground reservoirs. To accomplish this, one must be able to predict the performance of the reservoir under various production schemes. There are two essential issues, modeling and software architecture design, while developing a comprehensive oil reservoir modeling platform that should be an integration of subsurface models, facility network models and economic models. Effective subsurface models must be constructed to describe the complex geomechanical, physical, and multiphase fluid flow processes that accompany the various recovery mechanisms. Upscaling needs to be utilized to provide effective rock properties for coarse-grid models used for field-scale simulations. However, localized flow regimes at sub-coarse grid scales must often be resolved using local grid refinement techniques. Finite volume element methods for accurate resolution of localized geometrics can be coupled with cell-centered finite difference methods used in many existing simulators. Aspects of coupling different grids, different discretization schemes, and different physical equations via mortar techniques will be presented. Reservoir simulation is an integration of various technologies through the construction of a reservoir model as well as optimization of production strategies. A comprehensive oil reservoir modeling platform should be an integration of different software applications or components and its software architecture should be scaleable, extendable and should have the capability to create and modify a workflow. Beyond the traditional three-tier software architecture, data, application, and user-interface, separation of control and business logic through those three tiers is proposed to achieve those goals. The aspect of the software architecture design will be discussed.

Key Words. Eulerian-Lagrangian localized adjoint method, mixed finite element method, petroleum reservoir simulation, separation of control and business logic, three-tier software architecture

1. Introduction

With rapid advances in information technology and computing power, large-scale oil reservoir simulations become the routine work in upstream asset development. The objective of oil reservoir simulation is to understand the complex chemical, physical, and fluid flow processes occurring in an underground porous medium sufficiently well so as to be able to optimize oil production strategy that is usually constrained by the volatile oil prices. To do this, one must be able to predict

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the performance of the reservoir under various recovery scenarios. Consequently, a comprehensive oil reservoir modeling platform that is an integration of subsurface, facility network technologies and economics needs to be developed. There are two essential issues in development of this platform. An integrated model of reservoir, facility network and economic models must be efficiently constructed to yield information about complex subsurface phenomena and surface facility network accompanying different recovery scenarios. The software architecture design of the platform should be extendable to plug-in new software components and be flexible to create and to modify workflows that address various simulation scenarios. Among various important physical, mathematical and software development issues, we focus on the complex subsurface modeling processes and an improved software architecture design in this paper.

There are four major stages to the subsurface modeling process. First, a physical model of the flow processes is developed incorporating as much geology, chemistry, and physics as is deemed necessary to describe the essential phenomena. This requires the interaction of geologists, geophysicists, chemical and petroleum engineers, etc. Second, a mathematical formulation of the physical model is obtained, usually involving coupled systems of nonlinear, time-dependent partial differential equations. The analyses of these systems of differential equations are often quite complex mathematically. Third, once the properties of the mathematical model, such as existence, uniqueness, and regularity of the solution, are sufficiently well understood, a discretized numerical model of the mathematical equations is produced. A numerical model is determined that has the required properties of accuracy and stability and which produces solutions representing the basic physical features as well as possible without introducing spurious phenomena associated with the specific numerical scheme. Finally, a computer code capable of efficiently performing the necessary computations for the numerical model is developed. The total modeling process encompasses aspects of each of these four intermediate steps. This involves the multidisciplinary interaction of a wide variety of scientists. It is rare to find all of this expertise in one group or at one location. Thus the effective simulation of these problems should entail collaboration of scientists, often across disciplines and institutions, to address the enormous complexity of these models. Finally, the modeling process is not complete with one pass through these four steps. An optimized subsurface model should be developed by minimizing the difference between simulation results and field and lab observations by iterations through those four stages.

A comprehensive oil reservoir modeling platform should provide such a collaborative environment to support the multi-disciplinary collaborations. The aspects involved in the architecture design are three folds, an integrated central data repository that extracts, transforms and archives large amounts of incongruous data from domain specific data sources such as well log data, seismic data, well testing data, production data, rock and fluid properties, etc. and the flexibility to efficiently create, to manage and to modify a workflow that addresses various recovery scenarios. Beyond the traditional three tier software architecture, data, application and user-interface, separation of control and business logic through those three tiers is proposed to effectively and efficiently address those issues.

In this paper, we will discuss and survey some of the advanced numerical technologies that can be applied to improve the subsurface modeling as well as advanced software architecture design that allows effective integration of subsurface technologies. Some simulation results will be presented to illustrate those concepts.