AAPG Datapages/Search and Discovery Article #90174 CSPG©2014 CSPG/CSEG/CWLS GeoConvention 2012, (Vision) May 14-18, 2012, Calgary, AB, Canada

Interactive Visual Steering for Reservoir Geoscience and Engineering

Ali Karami Moghadam, Department of Chemical and Petroleum Engineering / Department of Computer Science, University of Calgary

akaramim@ucalgary.ca

Nicole Sultanum, Department of Computer Science, University of Calgary

nbsultan@ucalgary.ca

Zamir Martins Filho, Department of Computer Science, University of Calgary

zmfilho@ucalgary.ca

Daniel N. Miranda-Filho, PETROBRAS

daniel.miranda@petrobras.com.br

Hamidreza Hamdi, Institute of Petroleum Engineering, Heriot-Watt University / Department of Computer Science, University of Calgary

Hamdi.Hamidreza@pet.hw.ac.uk

John Chen, Department of Chemical and petroleum Engineering, University of Calgary

zhachen@ucalgary.ca

Mario Costa Sousa, Department of Computer Science, University of Calgary

smcosta@ucalgary.ca

Summary

As the scale, complexity and computational costs of reservoir simulations grow [1], reservoir engineers must be able to monitor the progress of the simulation and control or steer them during the run-time [2]. The utility and cost-effectiveness of these reservoir simulations is increased by transforming the traditional post-processing visualization and analysis of simulation results into integrated, interactive solutions [3]. The goal is to tightly integrate the interactive visualization techniques with the reservoir simulation systems and algorithms, allowing efficient and effective guidance during the reservoir analysis as the simulations occur [4]. The user will have the flexibility to compare different alternatives, to correct an unacceptable reservoir dynamic behavior or to seek an improved development alternative from both geological and flow simulation perspectives. This project has two main deliverables: (1) Fully Coupled Interactive Visual Steering for Black Oil, Compositional, Thermal, and Streamline Simulators; (2) Interactive Visual Steering for Geoengineering Well-Tests.

Introduction

The main objective of this work is to develop interactive software tools that support a generic framework for interactive visual steering to be integrated with existing high-end commercial reservoir simulators for black oil, compositional, thermal, streamline simulation studies, geoengineering well-tests, among others. By "closing the loop" between the user and the simulations, engineers are enabled to drive the reservoir simulation, visualization, analysis, and discovery process by observing intermediate results. They would be able to change the parameters, resolution or representation, and visualize the effects by experimenting with "what-if" scenarios [5]. This new process would provide an effective way to detect and verify uncertainties, correct unstable situations and readily terminate uninteresting runs. Computational steering frameworks have been proposed for various scientific and engineering domains [5]. The fundamental challenge is to construct a visual steering framework that can be seamlessly integrated with existing high-end commercial reservoir simulators, with minimal intervention in their complex architecture and code. The framework should handle multiple simulation models from at least one base case. It needs to provide efficient exchange of control parameters and access to results as the simulation progresses, without degrading the overall performance of the simulator.

Theory and/or Method

The proposed framework follows an iterative approach (Figure 1), in seven key steps. Initially, using the simulation and visualization tools, the user creates, respectively, the initial simulation (base case) and visualization models (steps 1 and 5). The steering process will follow in three phases.

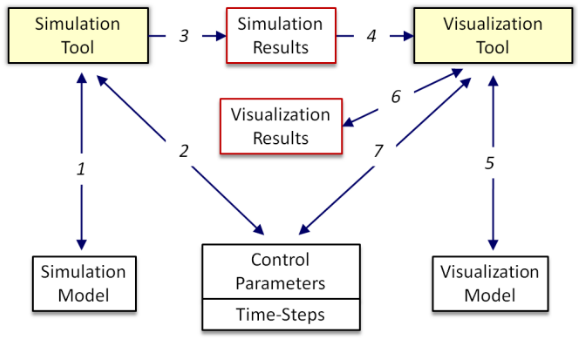
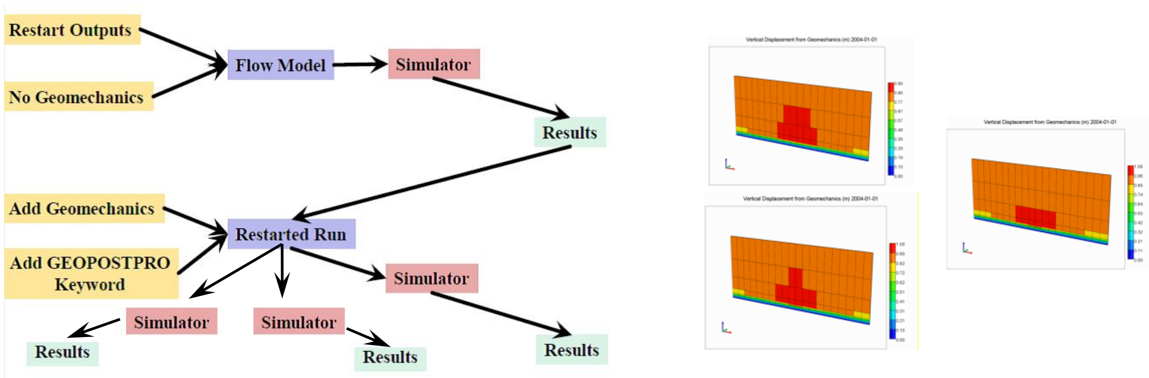


Figure 1: The reservoir visual simulation steering framework with seven iterative steps.

In the first phase, using the simulation tool, the user specifies the initial simulation control parameter values and produces the first simulation results (steps 2 and 3). In the second phase, simulation results are integrated with the visualization model (steps 4 and 5), generating the visualization results (step 6). In the third phase, the user can proceed, refining the control parameter values and manipulating specific simulation time-steps (step 7), generating new simulation results (using the current simulation model) and then returning to the second phase for subsequent new visualization results and exploratory visual analysis. Industry partners are providing the simulation tools, corresponding to three main systems for black oil, compositional, thermal, streamline, experimental/case-specific reservoir simulations, and geoengineering well-tests. They are also providing various simulation case studies with varying degrees of size and complexity. An optimized parameter and data exchange interface layer is being developed and integrated with the simulators data and solver interfaces. This visual steering framework will permit re-starting and management of new simulation runs from any intermediate step during the process creating corresponding derived cases. As multiple derived cases become available, they may be analyzed by comparing or operating on images from different derived cases and their respective base cases. Each derived case can lead to further derived cases as part of a *derivation tree* [6]. At user discretion, any derived case may be transformed into a new base case where the sequence of controls includes the controls pertaining to the base case and all the control modifications applied as part of any subsequent derivations.

Examples

(1) Geomechanical Post Processing -- Using the CMG Ltd.'s new geomechanical post processing feature, the visual steering framework helps the user to run a STARS or GEM flow model without geomechanics as the base case, and then use the result of this calculation to initiate running other instances of the model with geomechanics module enabled without re-running the flow model. This way, the associated geomechanical attributes are calculated from the initial flow model run and the input file can be used as a template for creating other new inputs that will cover different possible geomechanical parameter combinations (Figure 2(a)). This is an effective one-way coupling option as the flow model is not being run over and over for the geomechanical outputs to be sent to and iterated with.



(a) (b)

Figure 2: (a) Schematics of geomechanical post processing integrated with the visual steering framework (Courtesy of CMG Ltd); (b) Comparison of vertical displacement from geomechanics for 3 different geomechanical scenarios.

This is specifically helpful where geomechanical properties are uncertain and there is a need to have multiple geomechanical runs where geomechanical properties are varied to determine their effect on stresses and strains associated with the model. The simulation results below show the study of the change at surface in terms of heave from the injection of Super-Critical CO2 in a saline aquifer [10]. Since the model is 1-way coupled, anything can be defined or changed in the geomechanics definition without needing to worry about how flow results would change. Here, the result clearly shows the difference in vertical displacement calculation from geomechanics after 4 years, using three different geomechanical scenarios based on the same case (Figure 2(b)).

(2) Geological Well-Testing – The term "geological well-testing", in a broader sense, can be used instead of "numerical well-testing" [8]. This is referred to the numerical simulations of transient tests by setting up the detailed geological models within which different heterogeneity scales are spatially distributed in the model [7]. The complex fluid implications can also be deliberated, which gives the unique opportunity to investigative the competing effects of the geology and fluid in altering the dynamic behaviour of the well. This process requires a "geoengineering" workflow in order to integrate the multi-scale and multi-domain information (e.g. Geology, Geophysics and Engineering) and to constrain the well-test modelling and interpretation within a unified framework (i.e. a geological model). Meanwhile, the analytical methods are the pre-steps to numerical well-tests and are still relevant for most of the realistic petroleum reservoirs [9]. Figure 3 presented by Corbett et al. [7] shows a geoengineering workflow for well-test interpretation. A detailed geological model contains the multi-scale geological and geophysical information within an integrated platform. The dynamic transient response of the model can be match against the real well test data. A match can be achieved by structural and/or property perturbations. Therefore, a basic interactive visual steering is of natural need for a reservoir geoengineer to co-visualise the well test response and the reservoir model to define the volumes, perturb the structures or properties, re-run the transient flow simulations and attain the reliable match. An example of structural perturbation is the location of a sub-seismic fault which can be moved within the architectural framework of the reservoir model.

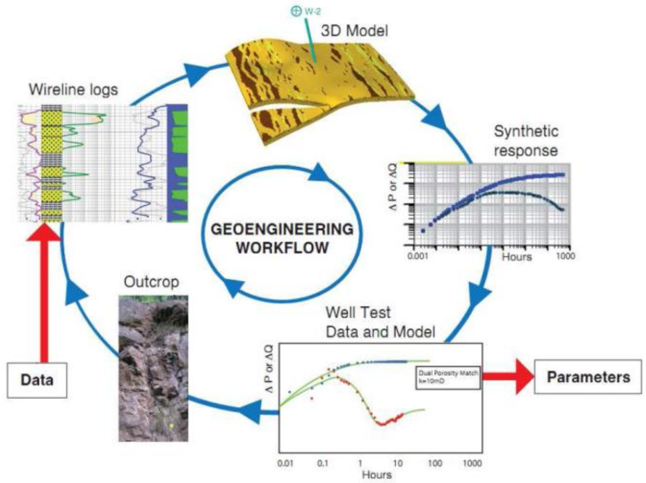


Figure 3: The geoengineering workflow used in geological well-test interpretation [7].

Conclusions

As in today's petroleum industry, great understanding of the geology of the hydrocarbon reserves and also accurate simulation of the fluid flow and geomechanical effects in the porous media play a vital role in formulating initial development plans, history matching and optimising future production and in planning and designing enhanced oil recovery projects, the visual steering framework provides an outstanding platform for geologists and reservoir engineers to come closer and collaborate together, compare different alternative scenarios, correct errors, and look for improved development strategies from all geological, geomechanical and flow simulation perspectives. By providing two case studies, one coupled with fluid flow and geomechanical simulation and one with geological well-testing, we showed that the visual steering framework enables its users to study and manage several different scenarios in an organized and meaningful fashion and therefore save a considerable amount of time and of course make them less prone to error. This is done by enabling them to have a greater control on the parameters of the simulation, observing intermediate results, keeping track of all the changes, and visualizing, analyzing and making comparisons of the results on the go and/or when the simulations are over.

Acknowledgements

This research is supported by the NSERC/Alberta Innovates Technology Futures (AITF)/ Foundation CMG Industrial Research Chair program in Scalable Reservoir Visualization.

References

[1] F. Abraham, W. Celes, 2009, Distributed Visualization of Complex Black Oil Reservoir Models. Eurographics Symposium on Parallel Graphics and Visualization (EGPGV '09), 87-94

[2] O. Kreylos, A. M. Tesdall, B. Hamann, J. K. Hunter, K. I. Joy, 2002, Interactive Visualization and Steering of CFD Simulations. *8th Eurographics Workshop on Virtual Environments*

[3] D. Dopkin, H. James, 2006, Trends in Visualization for E&P Operations. *First Break*, 24(3).

[4] K. Matkovic, D. Gracanin, M. Jelovic, H. Hauser, 2008, Interactive Visual Steering –- Rapid Visual Prototyping of a Common Rail Injection System. *IEEE Transactions on Visualization and Computer Graphics*, 14(6): 1699-1706

[5] J. D. Mulder, J. J. van Wijk, R. van Liere, 1999, A Survey of Computational Steering Environments. *Future Generation Computer Systems*, 15(1): 119-129

[6] J. Waser, R. Fuchs, Hr. Ribii, G. Blöschl, M.E. Gröller, 2010, World Lines. *IEEE TVCG*, 16(6): 458-1467

[7] Corbett, P. et al , 2010, Limitations in numerical well test modelling of fractured carbonate rocks, SPE EUROPEC/EAGE.

[8] H. Hamdi, 2012, "Illumination of Channelized Fluvial Reservoirs Using geological Well-Testing and Seismic Modelling", PhD thesis, Institute of Petroleum Engineering, Heriot-Watt University, UK

[9] G. Stewart, 2011, *Well Test Design & Analysis*: Tulsa, Oklahoma, PennWell, 1544 p.

[10] D. Tran, V. Shrivastava, L. Nghiem, B. Kohse, CMG, 2009,Geomechanical Rick Mitigation for CO2 Sequestration in Saline Aquifers, SPE 2009 Annual Technical Conference and Exhibition, New Orleans, Louisiana, USA.