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Application of Flow Diagnostics for Carbon Dioxide Transport in Porous Media

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Abstract—*Reservoir simulation workflows contain significant elements of uncertainty, particularly in the geological description of reservoir geometry and petro physical parameters such as permeability and porosity. To accurately account for uncertainty and span the range of likely outcomes, different equiprobable realizations should be kept as long as possible throughout a modelling workflow for CO_2 sequestration. Herein, we propose to combine two recent and quite different technologies to enable optimization of multiple realizations. In particular, it is possible to adjust accuracy dynamically from inexpensive proxy models provided by pure multiscale and flow diagnostics, via more accurate iterated multiscale solutions and incompressible flow, to fully-implicit solvers that incorporate the relevant flow physics. Flow-diagnostics, as referred to herein, are computational tools based on controlled numerical flow experiments that yield quantitative information regarding the flow behavior of a reservoir model in settings much simpler than would be encountered in the actual field. In contrast to output from traditional reservoir simulators, flow diagnostic measures can be obtained within seconds. The methodology can be used to evaluate, rank and/or compare realizations or strategies, and the computational speed makes it ideal for interactive visualization output. We also consider application of flow diagnostics as proxies in optimization of reservoir management workflows. In particular, based on finite volume discretizations for pressure, time-of- flight (TOF) and stationary tracer, we efficiently compute general Lorenz coefficients (and variants) which are shown to correlate well with simulated recovery. For efficient optimization, we develop an adjoint code for gradient computations of the considered flow diagnostic measures. We present several numerical examples including optimization of rates, well-placements and drilling sequences for two and three phase synthetic and real field models. Overall, optimizing the diagnostic measures imply substantial improvement in simulation-based objectives.*

1. INTRODUCTION

Activities such as burning of fossil fuels along with cement making have led to a significant increase in the CO2 concentration in the atmosphere since the start of the industrial revolution [IPCC 2007]. CO2 being a strong and long-lived Green House Gas (GHG), its increased concentrations in the atmosphere has led to increase in the global temperature [IPCC 2007]. Carbon Capture, Storage and Sequestration are presently viewed as an important strategy to reduce the concentration of CO2 in the atmosphere. One way to conflict climate change is to prevent the release of CO2 to the environment by storing it in natural underground reservoirs. This paper describes the concept and outlines some of the issues involved in estimating the trapping of CO2 in geological formation. CO2 emitted by large sources, such as power plants and other industrial processes, could be captured and stored underground using Depleted oil as well as gas fields, Coal seams and deep saline reservoirs. Shaping the maximum amount of CO2 that can be injected and firmly contained is a key matter. When injected into the geological formations, density differences will drive CO2 to form a separate (the CO2 plume) mobile phase, which is driven upwards by buoyancy . Reservoir simulation, in particular, can to a large extent realistically describe fluid flow in the reservoir on the time scale associated with reservoir management and offers a means of forecasting recovery based on available data and a set of modeling assumptions about the reservoir. However, to be able to span the range of possible and likely scenarios, the reservoir engineer must be able to efficiently validate and verify alternative hypotheses, systematically explore the parameter space, and assess how recovery forecasts are influenced by uncertainty in assumptions, data, and operating constraints. Time-of-flight and and derived quantities have traditionally been associated with streamline simulation (Datta-Gupta and King 2007) and have been used for ranking and upscaling (Idrobo et al. 2000; Ates et al. 2005; Shook and Mitchell 2009), identifying reservoir compartmentalization (He et al. 2004), rate optimization (Thiele and Batycky 2003; Park and Datta-Gupta 2011; Izgec et al. 2011), and flood surveillance (Batycky et al. 2008).

2. FLOW DIAGNOSTICS

The term flow diagnostics, as we use it herein, refers to methods that can be exploited to reveal information about communication and flow patterns in a reservoir without running a full dynamic simulation. There are several methods that can be characterized as being flow diagnostics. One recent idea is to use fast-marching methods to compute pressure propagation, from which one can determine radius/depth of investigation (Zhang et al. 2013), provide dynamic ranking of model ensembles (Sharifi et al. 2014), verify dynamic upscaling (Sharifi and Kelkar et al. 2014), and perform well testing (Lallier et al. 2014). Herein, however, we focus on methods that analyze the properties of a single static flow field.

2.1. Time Of Flight

To study how heterogeneity affects flow patterns and define natural time-lines in the reservoir, it is common to study the so-called time-of-flight (TOF), i.e., the time it takes an imaginary particle released at an inflow boundary or at a perforation of an injector to reach a given point in the reservoir(I. S. Duff and J. K. Reid et al. 1978). Time-of-flight is usually associated with streamline methods.

2.2. Tracer partitions:

Communication patterns within the reservoir can be determined by simulating the evolution of artificial, neutral tracer with concentration c into injection wells or fluid sources. A simple tracer test is to set the tracer concentration equal one in only one injection well, a well completion, or (parts of) an inflow boundary and compute the steady-state that the solution approaches at late times. The steady state cannot generally be achieved in field experiments, but is easy to compute numerically. Hence, one can easily partition a model into swept volumes by repeating the tracer test for each well, well completion, or part of the inflow boundary. Moreover, one can equally well reverse the flow field and compute similar tracer distributions associated with producers and outflow boundaries.

3. COMPUTATIONAL METHODS

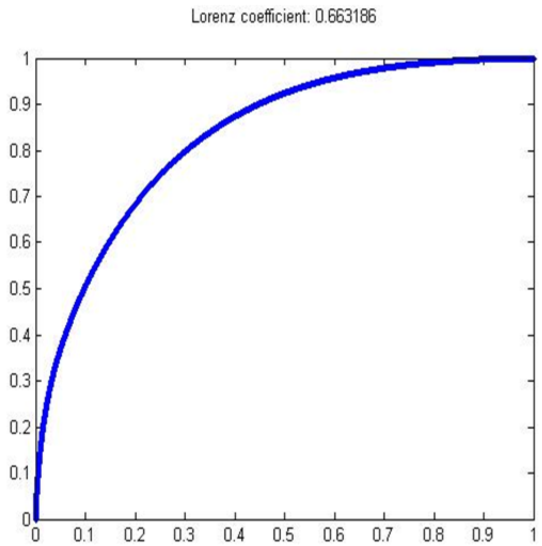
Under the hypothesis of incompressible flow, the time-of-flight and steady-state tracer equations are linear transport equations . Introducing a standard single-point upwind (SPU) finite-volume discretizations results in reducible, block-structured linear systems $Ax = b$ that can be solved very efficiently. This Cartesian box model consists of approximately 1.1 million grid cells and is used widely throughout the text as a standard point of reference for new simulation methods. In our setup we replace the central injector of the original five-spot well configuration by two injectors that are moved a short distance from the model center. Altogether, the flow-diagnostics computation will require one pressure solution, two time-of-flight solutions, one tracer solution with two different right-hand sides for the injectors, and one tracer solution with four right-hand sides for the producers. In MATLAB, computing the flow field took 7.3 seconds on a standard workstation PC using a highly efficient algebraic multigrid solver [S. Krogstad et al. 2011], whereas computing time-of-flight and tracers took 4.9 seconds with MATLAB's standard direct solver, which utilizes the special structure of the equations and solves for multiple right-hand sides in one pass. To understand the structure of the linear system, we can view the fluxes from the flow problem as edges in a directed graph, and then use a depth-first search of the flux graphs (topological sort) to permute the discretization matrix A, which is identical for the time-of-flight and tracer equations, to a lower block-triangular form $L = P APT$. Solving the linear systems thus reduces to an efficient block wise back-substitution algorithm1 that inverts a sequence of smaller linear problems corresponding to each irreducible diagonal block of L. The size of each diagonal block is given by the number of degrees of freedom in the corresponding grid cell . The resulting computational complexity is close to optimal in the linear case.

4. VISUALIZATION OF FLOW DIAGNOSTICS

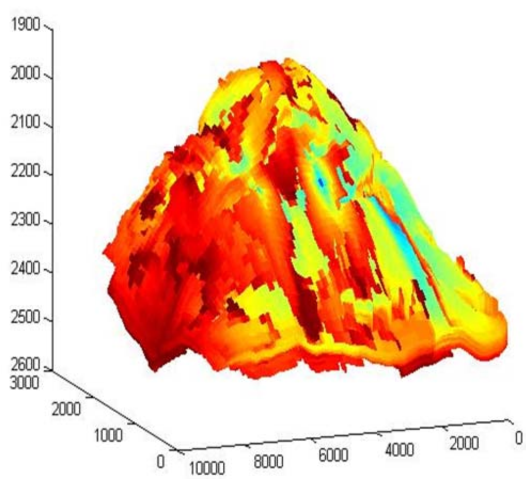
The most obvious use of tracer partitions and time-of-flight values is to use these cell-based values as a basis to provide improved visualization of flow patterns. Tracer partitions have utility in identifying the region swept by an injector or the fraction of fluid production attributed to a particular injector or completion. Likewise, drained regions and injection allocation can be determined by reversing the flow field. Drainage and swept volumes are defined using a majority vote over tracer concentrations that assign each cell to a specific injector or producer. Communication between wells is obtained by intersecting drainage and swept volumes, and the resulting volume partition can be used to identify the pore volume associated with each well pair, or to compute well allocation factors, i.e., the fraction of the producer's inflow that can be attributed to a given indicator. In the bottom row the pore volumes shared by producer P5 and injectors I1 to I3 , whereas the flux allocation in P5 is shown as a function of depth. The figure also demonstrates how a very intuitive visualization of the evolution of injected fluids is obtained by combining swept volumes with the forward time-of-flight[I. S. Ligaarden et al. 2011] as part of a simple interactive visualization tool. In our simple prototype tool, all flow diagnostics necessary is computed up front and can be recalculated interactively if the user chooses to modify the well configuration using the simple editor that is part of the tool. Whereas the fast simulation responses allow for great interactivity in MATLAB for models with tens of wells or individual perforations and model sizes up to a million cells, it is generally not possible for more complex models with hundreds of wells or individual perforations or multimillion cells. Here, flow diagnostics should be computed on demand, utilizing the reordering methods to effectively localize the computation of time-of-flight and tracers to regions of interest, e.g., when inspecting individual perforations. Likewise, pressure solutions can be recomputed efficiently using a multiscale method [A. F. Rasmussen et al. 2012], or possibly using model-reduction techniques tuned to previous flow simulations [L. W. Lake et al. 1989].

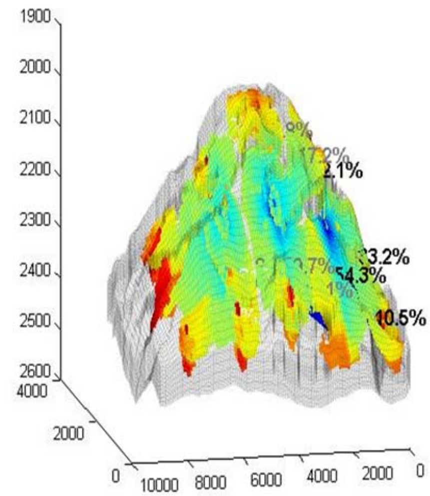
5. RESULTS

Since the flow-diagnostics computations are in essence incompressible single-phase simulations, we need to translate the limits and constraints from the multiphase model. Limits on bottom-hole pressure are adjusted based on the depth of the wells, and the rate-constraints are converted to reservoir conditions using the initial state of the reservoir. The well controls in the black-oil simulator operate according to reservoir volume rates. Because total injected and produced volumes are constrained to be equal, the reservoir pressure is approximately maintained and average pressure only varies twenty bar during simulation.

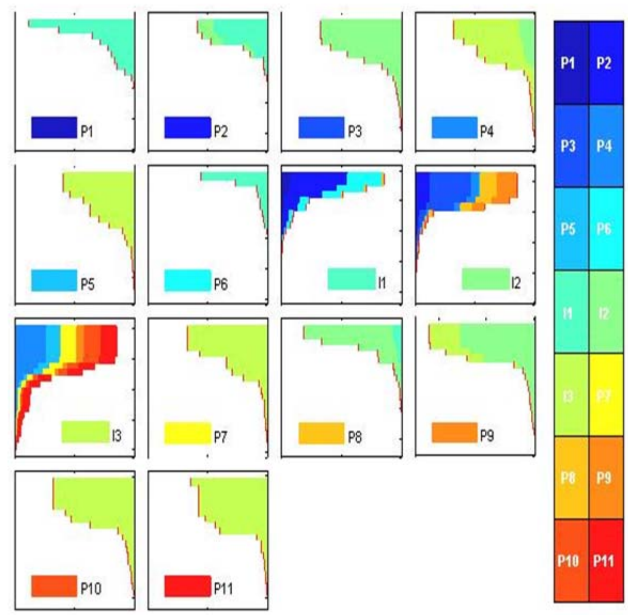


The above graph representsValidation of Chemical flood optimization based on the Lorenz coefficient for all 85 layers of the SPE10 model using four different fluid models. The left plot shows recovery factor before and after optimization for a viscosity ratio of five. The right plot shows the increase in oil recovery as a function of decrease in Lorenz coefficient for different Corey exponents and viscosity ratios.





The figures presents Chemical flood optimization for a shallow marine reservoir. Initial time steps, indicating that the major changes in the reservoir happen when the initial front starts to propagate.



Well controls for the optimized production strategies presented in above figure. Well names refer to the positions in the initial configuration. Notice that there are more than one optimal well position in this problem because of symmetry and because the Lorenz coefficient is not convex.

6. CONCLUSION

In this paper we have presented a computational methodology for optimization work- flows within reservoir management based on fast computation of pressure, time-of- flight (TOF), and stationary tracers. Flow diagnostics differ from traditional simulations in that there is no time-stepping, which means that valuable output can be produced in seconds. Fast response times together with visual-friendly output make approached based on flow diagnostics ideal for interactive ”what-if” exploration. In effect, more realizations and scenarios can be tested, while the number of traditional simulations can be reduced by eliminating the unfavorable ones at an early stage. This makes the methodology amenable for model ranking, interactive visualization and as proxies for optimization; herein, we have focused on the latter two. Flow diagnostics as presented herein has a lot in common with streamline methods, but an important advantage over streamline methods is that the equations are discretized directly on the simulation grid. Accordingly, potential problems related to streamline tracing and solution mapping on challenging (polyhedral) grids are avoided. Given the simplicity and utility of flow diagnostics, we generally recommend that reservoir simulators, as well as workflow tools for building reservoir models, implement these techniques and use them for (interactive) pre- and post processing.

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REFERENCES

[1] Thiele, M. R. and Batycky, R. P. 2003. Water injection optimization using a streamline-based workflow. In Proceedings of the SPE Annual Technical Conference and Exhibition, 5-8 October 2003, Denver, Colorado. doi: 10.2118/84080-MS.

[2] Idrobo, E., Choudhary, M., and Datta-Gupta, A. 2000. Swept volume calculations and ranking of geostatistical reservoir models using streamline simulation. In SPE/AAPG Western Regional Meeting, Long Beach, California, USA. SPE 62557.

[3] Datta-Gupta, A. and King, M. J. 2007. Streamline Simulation: Theory and Practice, volume 11 of SPE Textbook Series. Society of Petroleum Engineers.

[4] Batycky, R. P., Thieles, M. R., Baker, R. O., and Chugh, S. H. 2008. Revisiting reservoir flood-surveillance methods using streamlines. SPE Res. Eval. Eng., 11(2):387–394. doi: 10.2118/95402-PA.

[5] I. S. Duff and J. K. Reid. An implementation of tarjans algorithm for block triangularization of a matrix. ACM Trans. Math. Software, 4(2): 137–147, 1978.

[6] Lallier, F. L., Montouchet, M., Bergey, P., and Vignau, S. 2014. An efficient well test forward model based on the fast marching method – application to geomodel sorting. In ECMOR XIV – 14th European conference on the mathematics of oil recovery. EAGE. doi: 10.3997/2214- 4609.20141869.

[7] Sharifi, M., Kelkar, M., Bahar, A., and Slettebo, T. 2014. Dynamic ranking of multiple realizations by use of the fast-marching method. SPE J. doi: 10.2118/169900-PA.

[8] Zhang, Y., Yang, C., King, M. J., and Datta-Gupta, A. 2013. Fast-marching methods for complex grids and anisotropic permeabilities: Application to unconventional reservoirs. In SPE Reservoir Simulation Symposium, 18-20 February, The Woodlands, Texas, USA. doi: 10.2118/163637-MS.

[9] S. Krogstad. A sparse basis POD for model reduction of multiphase compressible flow. In 2011 SPE Reservoir Simulation Symposium, The Woodlands, Texas, USA, 21-23 February 2011, 2011.

[10] L. W. Lake. Enhanced Oil Recovery. Prentice-Hall, 1989.

[11] K.-A. Lie, S. Krogstad, I. S. Ligaarden, J. R. Natvig, H. Nilsen, and B. Skaflestad. Open-source MATLAB implementation of consistent discretisations on complex grids. Comput. Geosci., 16:297–322, 2012.

[12] K.-A. Lie, S. Krogstad, I. S. Ligaarden, J. R. Natvig, H. M. Nilsen, and B. Skaflestad. Open source MATLAB implementation of consistent discretisations on complex grids. Comput. Geosci., 16:297–322, 2012.

[13] K.-A. Lie, H. M. Nilsen, A. F. Rasmussen, and X. Raynaud. Fast simulation of polymer injection in heavy-oil reservoirs based on topological sorting and sequential splitting. In 2013 SPE Reservoir Simulation Symposium, The Woodlands, Texas, USA, 18-20 February 2013, 2013. SPE 163599-MS.