Introduction

Reservoir full-field models are typically large (millions to hundreds of millions of cells), making them computationally demanding to simulate. Modern workflows used for uncertainty analysis or history matching require running such models even hundreds of times, amplifying the amount of resources required to perform the studies. One of the factors unnecessarily prolonging the length of a significant portion of simulations is timestep cuts. Unlike in other fields, the optimal timestep length in reservoir simulation cannot be easily calculated and is usually determined using heuristics (Crumpton, 2019). Both too short and too long timesteps lead to unnecessary calculations and an increase in the simulation runtime.

In this work, a look-ahead timestep size selection method is introduced, which uses smaller coarsened proxy models to guide the timestep selection of the original high-fidelity model. This work capitalizes on the coarsening of models that retain the main characteristics of the simulation run, where a coarsened model is generated and is run simultaneously with a fine-grid simulation run. The timestep size chosen for the proxy model is used to guide the timestep selection of the fine-grid model. The look-ahead method of utilizing the coarsened model results in a reduction of the timestep cuts in the fine-grid simulation run that would have otherwise occurred. The proposed method has been tested on several synthetic and real-field reservoir models and shown to result in a reduced number of timestep cuts based on the input from the coarsened model. A significant reduction of timestep cuts results in computational cost savings and enhanced runtime as wasted Newtonian and linear iterations are avoided.

Background

In reservoir simulation, mathematical models are comprised of sets of coupled, non-linear Partial Differential Equations, which are transformed into a linear system of algebraic equations (Kayum et al. 2019). The equations are solved numerically at each simulation timestep. Reaching convergence is dependent on many factors, such as the solver type, preconditioning method, solver tolerances, and the timestep size chosen. The timestep size selection has a significant impact on the convergence behavior of the simulation. If the timestep size is chosen to be too small, the high computational cost will result in an unnecessarily high number of timesteps taken. If its size is too large, the linear system can become difficult to solve, resulting in convergence issues for the non-linear system and consequently timestep cuts and redundant computations. The timestep size selection is critical to the simulator’s performance and finding the right balance between performing unnecessary work (timestep too short) and increasing the complexity of the problem to the point where it cannot be solved efficiently (timestep too long) is one of the major challenges to reducing the simulator runtime. In fully implicit reservoir simulation, nonlinearity exists especially in dual-porosity, dual-permeability reservoirs. The nonlinearity results in timestep selection that is guided by heuristics, which are usually based on physical constraints such as the previous timesteps, maximum pressure, and saturation changes. This method can be very effective but can lead to many timestep cuts, and sometimes even failure of the simulator (Crumpton, 2019).

Method

Grid coarsening

The method presented in this work uses a reduced-order proxy model to help determine the timestep size leading to runtime reduction on the full-scale model. The proxy model is generated by decreasing the number of grid blocks used to perform the simulation. The optimal coarsening averages the fine-scale properties into larger cells while preserving the flow properties of the model. Having fewer grid-cells in a reservoir model generally results in fewer calculations and consequently a reduction in simulation runtime. Since the high fidelity of some regions of the model cannot be compromised, the reservoir simulation runs cannot be coarsened past a certain threshold. This is particularly important in timestep selection because the convergence behavior of the model strongly depends on nonlinearities occurring in a few problematic cells. When uniform coarsening is applied, many of these nonlinearities are attenuated, and in general, a bigger timestep can be achieved.
While it is possible to use sophisticated upscaling methods to minimize the error originating from resolution reduction of the and even use coarsened models for history matching (Taware et al. 2011), in this work, simplified coarsening schemes were used. As many nonlinearities controlling the maximum attainable timestep size originate from the well calculations, cells containing well perforations were not coarsened. Other areas of the model were coarsened uniformly. Even using such a simplified scheme, it has been noticed that certain characteristics are found to be similar. One of such properties, the timestep size, is then taken advantage of to speed up and enhance the fine-grid simulation run by avoiding computationally expensive timestep cuts.

**Timestep behavior similarity using proxy models**

The first coarsening scheme worth noting is a 2x2 coarsening of cells that do not contain any wells, as illustrated in Figure 1. Using this strategy, the total number of cells was reduced down to 25% of the original number, and the runtime was sped up 2.3 times.

![Figure 1](image1.png)

Figure 1 Grid of (a) fine-grid case, (b) 2x2 coarsening excluding wells, (c) 4x4 coarsening except for the radius around the region of interest.

Another more sophisticated strategy is to identify the most constraining wells and maintain the resolution in their area. The grid resolution of 20 cells from the identified well was retained, and other wells within 60 cells of it were preserved while all the other cells were coarsened into 4x4 blocks. This approach resulted in a 432 thousand cell model (14% of the original).

![Figure 2](image2.png)

Figure 2 Illustration of the timestep size of the fine-grid model and coarsened grid proxy model
Figure 2 demonstrates that the timestep size of a model coarsened in such a way, although not exact, is very representative of the fine-grid model. This resemblance is what the presented method capitalizes on to guide the fine-grid simulation run’s timestep selection further highlighting that much smaller and faster models can be automatically created that will exhibit predictive capabilities for timestep selection on the high-fidelity models.

The Workflow

Two workflows of using the presented method are proposed: sequential and concurrent use of reduced-order and high-fidelity models. In the sequential approach, the coarsened model is first run, timestep behavior is registered, and then reused to benefit the high-fidelity case. The concurrent approach is that as the reduced-order model runs faster and on a smaller amount of compute resources, both models can start simultaneously. The proxy model will quickly overtake its detailed counterpart allowing to utilize the timestep information as both simulation progress. While both approaches lead to an increase in the total amount of compute resources required, on models where timestep cuts pose a performance issue, the benefits will be achieved due to the shorter time required to finish the simulations.

Results

The method was tested on real-field models. The results shown are from a real-field, oil/water/gas, dual-porosity, and dual-permeability model with 1068 wells simulating the period between 1940 and 2045. Figure 3 (left) illustrates the timestep cuts throughout the simulation run of the fine-grid before and after utilizing the method. The reduction in timestep cuts is evident where the new fine-grid simulation run has resulted in a 50% reduction in timestep cuts.

The performance gain of the timestep cut reduction is shown in Figure 3 (right), where the elapsed time is illustrated. It can be seen that the performance improvement is up to 13% of the overall simulation runtime and is correlated with the number of timestep cuts that a simulation run undergoes.

The accuracy of the method is quantified by looking at the average field pressure, which is illustrated in Figure 4. It can be seen that the base fine-grid model and the optimized fine-grid model run produce identical average field pressure.

Figure 3 Left: Timestep cuts of the fine-grid model (blue), proxy model (green) and fine-grid model using proxy model timestep size recommendations (red); Right: Elapsed time of fine-grid model (blue), proxy model (green) and fine-grid model using proxy model timestep size recommendations (red)
Future Work and Conclusions

Reservoir full-field models are typically large (millions to hundreds of millions of cells), making them computationally demanding to simulate. Reservoir simulation engineers constantly run simulations with these large models to perform uncertainty analysis. In this work, wasted Newtonian iterations resulting from non-convergence are targeted. If the timestep size can be predetermined, wasted Newtonian iterations can be avoided, resulting in an enhancement in the simulator runtime. In cases where the simulation has no timestep cuts, no improvement in runtime will be seen and the advantage of the method is evident in cases where timestep cuts are very high. The method results in fewer timestep cuts, reduction in wasted iterations, and consequently, faster simulation turnaround time.

This work could be enhanced in the future by having two coarsened models, the first capturing the details of the historical wells which will be active during the historical period of the simulation while coarsening the prediction related wells. The timestep selection of this coarsened model run can be outputted to be used by the fine-grid simulation during the historic run. The second model would emphasize the details of the prediction wells, which will be refined, and its recorded timestep would be used to guide the fine-grid model during the corresponding period of the simulation. The results of the coarse model simulation can be compared with the fine model during the simulation. If the two models start to diverge, in terms of timestep response (fine model starts cutting timesteps) or simulation key performance indicators such as oil production rate or a number of active wells, the coarse model can be restarted with the fine-scale model input at the time, and the coarse model is re-run.

References