

Coupling Reservoir Simulation and Geomechanical Modeling to Improve the Analysis of Hydrocarbon Reservoir Behavior

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Abstract: *In oil and gas field development, reservoir simulation is applied to accurately predict and analyze fluid flow during production. The results of reservoir simulation can be used as input for 4D geomechanical modelling to obtain the earth's mechanical response such as reservoir compaction. However, in such a one-way coupling scheme, the geomechanical response of a system has no influence on the reservoir simulation, whereas in reality mechanical and flow behaviors influence each other.*

In two-way coupling, this dependency is taken into account. We perform two-way coupling using the JewelEarth™ platform, connecting CMG's IMEX Blackoil simulator and Abaqus for the geomechanical simulations. In the coupling process, we update (among others) the available pore volume and pore pressures in the reservoir at each time step, while not changing the fluid accumulations (masses). Optionally, we also continuously enhance the reservoir simulator's internal geomechanical estimate with a pseudo-compressibility based on the modelled geomechanical response.

The differences between one-way and two-way coupling implementations are very clear when applied on a benchmark model used by numerous authors. However, we also recognize the benchmark model has been designed to show the largest possible effect of two-way coupling. When changing only a few parameters to more realistic properties, the one-way and two-way coupled results are much more alike. This shows that, while two-way coupling may be advantageous in some rare cases, it may not be worth the extra simulation time and effort for each hydrocarbon reservoir.

Keywords: *Two-way Coupled Modeling, Reservoir Geomechanics, Subsidence, Compaction*

1. Introduction

In oil and gas field development, reservoir simulation is applied to accurately predict and analyze fluid flow during production. These reservoir simulation results (pressure response, saturations and temperature over time) can be used as boundary conditions in 4D geomechanical modelling, and to analyze the full mechanical response of a reservoir and its surroundings (Holland and van der Zee, 2015, van der Zee et al., 2014). This kind of modelling is termed one-way coupling, and is used in a wide range of applications such as estimating subsidence and subsidence rates, fault

stability assessment and stress determination in depleted reservoirs. These stresses are used in studies of wellbore stability for infill drilling and sand production prediction.

However, in one-way coupling, the geomechanical response of the system has no influence on the reservoir simulation results, whereas in reality, they influence each other. The deformation of the reservoir rock leads to changes in porosity and permeability. These deformations are driven by pore pressure and/or temperature changes, but are not necessarily similar or homogeneous through the reservoir because of geometrical effects such as arching. This means that a coupling between the geomechanical model and the reservoir model can lead to very different results than only using a reservoir model (even if this includes “geomechanical options” on the reservoir level only such as irreversible deformation and hysteresis). These dependencies are taken into account in so-called two-way coupled models, in which the geomechanical response is used to update the reservoir simulation. Various numerical solutions such as iterative and fully-coupled were used in the past to solve the governing equations of thermal-hydro-mechanical simulations (Gutierrez and Lewis, 1998; Dean et al., 2006; Inoue and Fontoura, 2009).

Modeling the interaction between geomechanics and reservoir production requires not only modeling of the reservoir rock and corresponding changes in porosity but of the surrounding rocks or faults as well. The geomechanical simulation of these surrounding rocks (consisting of over-, side-, and underburden) is important to ensure that the boundary conditions of the model are sufficiently specified. The thickness of the overburden and the properties associated with the overburden account for the compaction within the reservoir and the subsidence seen at the surface. The sideburden actively influences the stress path and compaction of the reservoir. With a sideburden of high Young’s modulus, some of the overburden load is transferred from the overburden to the sideburden, and arching can be observed. Arching leads to uneven application of the vertical stress from the overburden above the reservoir. Similarly, the underburden directly supports the sideburden and has a large influence on the stress distribution and compaction within the reservoir (Samier et al., 2008). Samier et al. (2008) states that the characterization of reservoirs with complex nonlinear stress paths or properties is best managed by solving the equations of reservoir simulation and geomechanics in a separate and sequential manner, coupled through the pore volume of the cells.

While fully-coupled modeling (also called implicit modeling) solves all of the governing equations at once in rigorous fashion, typically leading to accurate results, the drawback is found in terms of convergence time and numerical stability. Over the years, dedicated simulators (reservoir, geomechanical) were built up with the most accurate physics in their respective domain. Explicit coupling takes advantage of this by using the best simulators in each field and coupling through a common platform such as the JewelEarth™ platform. While Abaqus is an industry leader in geomechanical modeling and CMG’s IMEX is a leading commercial reservoir simulator, the true benefit in explicit coupling is in computational time savings without sacrificing physics. Furthermore, in the oil and gas industry, most end users prefer to use a company-approved simulator dedicated to a certain domain (e.g. reservoir simulation) and are not able to easily switch to another simulator.

Gutierrez and Lewis (1998) were the first to develop a fully-coupled model with stiff under, over and sideburdens surrounding a weak reservoir zone. Dean et al. (2006) were one of the first to compare the various methods of coupling. Inoue and Fontoura (2009) extended the findings of Dean et al. (2006) to describe a method of coupling IMEX and Abaqus. Using the pressures and

saturation from the reservoir simulation, the nodal forces are calculated and written into the Abaqus CAE deck as an input file using the *CLOAD keyword. The finite element mesh will solve the displacement at each of the nodes and the stress state at each integration point. From these strains, a pseudo-compressibility field is calculated. From the changes in strain, the porosity in the reservoir simulator and the corresponding pseudo-compressibilities per cell are written to the IMEX input deck via the PORO and ROCK keywords (Inoue and Fontoura, 2009).

Lautenschlager et al. (2013) later improved the work of Inoue and Fontoura (2009) and advanced the coupling between IMEX and Abaqus. They observed that the porosity updating done in IMEX from changes in the pore pressure field does not take into account the correct starting reference pressure. While the variation in pressure and changes in volumetric strain are utilized in the pseudo-compressibility parameter, the initial reference porosity to which the pseudo-compressibility is applied is incorrect because of the incorrect starting reference pressure. The porosity is linked only to the reference pressure (in-situ reservoir pressure) assigned in the data input, leading to incorrect starting porosities during the modeling time steps.

1.1 Objective

The objective is to build an iterative two-way coupled system using Abaqus and IMEX. This system is verified using the benchmark model developed by Gutierrez and Lewis (1998). After verification, this system is used to further improve the coupling by adding pseudo-compressibility to the workflow. Finally, the study is extended to less drastically heterogeneous reservoir zones to show the necessity of understanding the appropriate setting and situation that require two-way coupled modeling.

2. Methods

The two-way coupled system developed comprises two separate models which can also run uncoupled on their own. The Abaqus geomechanical model comprises the reservoir unit, but also the under-, side- and overburden; the IMEX reservoir simulation model comprises only the reservoir unit.

2.1 Benchmark Model set-up

The benchmark model originally developed in Gutierrez and Lewis (1998) was later used as the benchmark model for mechanical and flow coupling by Dean et al. (2006) in a paper that compared the various approaches for coupled reservoir geomechanics. The benchmark model comprises a weak reservoir surrounded by non-reservoir rock with a Young's modulus two orders of magnitude higher.

2.1.1 The Geomechanical Model

The finite-element mesh describing the benchmark model has a vertical extent of 10,450 ft and a lateral extent of 42,000 ft in the x- and 21,000 ft in the y-direction. The top of the model is at 0 ft,

and the overburden is represented by five layers of vertical thickness of 4,000, 3,000, 2,000, 800 and 200 ft. The reservoir consists of two zones of 125 ft each. The underburden is represented by a 200-ft-thick section. The authors are aware that the base of the model is too close to the reservoir for valid geomechanical modeling, but it was decided to follow the original benchmark model with these dimensions for comparison purposes.

A workflow was constructed which enabled for freedom in mesh generation, and therefore, the model was meshed with 2nd order pore-pressure tetrahedrons (C3D10MP). Hexahedrons are a better choice for the chosen very regular mesh, but the tetrahedrons were used for easier integration with the available functionality in the JewelEarth platform. The large scale view of the model is presented in Figure 1.

To obtain a sharp transition in pore pressures between the reservoir and the over-, side- and underburden, the mesh around the reservoir was split and tied together without the pore pressure degree of freedom using the partially undocumented keyword:

*TIE, NO PORE PRESSURE.

The Young's modulus in the reservoir region was 1×10^4 psi (68.9 MPa). The over-, side- and underburden have a Young's modulus of 1×10^6 psi (6.89 GPa). Poisson's ratio is 0.25 in the entire model. The density of all rock in the model is set to 2.7 g/cm^3 . The vertical stress at the surface is set to 14.7 psi (which means no water load – only atmospheric). Finally, the bottom and the sides of the grid are constrained with zero normal displacement, and there are zero tangential stresses on the faces of the Abaqus mesh.

The initial stress state is generated using the two- step approach as described in van der Zee et al., 2011. In the first step, a vertical stress is calculated using the density in the model, followed by a second step where the calculated effective vertical stress is used to pre-describe the horizontal stresses with a K_0 factor of 0.5. These steps combined with a *geostatic step with a low displacement tolerance (utol) generates an initial stress field with hardly any deformation before introducing the pore pressure perturbations from the reservoir simulation.

The one-way coupled run of this geomechanical model uses the pore pressures as calculated in the reservoir model (section 2.1.2) and applies these as degrees of freedom in the reservoir section of the model. The pore pressure on all the nodes outside the reservoir model are fixed at their initial pressure. For each pore pressure step, a steady-state *Soils step is run to obtain the deformations and stresses for the given pore pressures.

2.1.2 The Reservoir Model

The reservoir grid comprises 22x22x10 orthogonal cells, with cell lengths of 1,000 ft in the x-direction and 500 ft in the y-direction; each reservoir layer in the z-direction was 25-ft thick. The horizontal and vertical permeabilities are 100 and 10 mD, respectively, and held constant for the validation modeling. The in-situ porosity is 25% in all grid cells. Assuming the reservoir behaves according to uniaxial strain, the explicitly coupled simulation uses values of $3.33 \times 10^{-4} \text{ psi}^{-1}$ for the reservoir compressibility and $3.33 \times 10^{-6} \text{ psi}^{-1}$ for the non-pay compressibility, as defined in the benchmark papers. It should be noted that these values are incorrect with respect to the actual inverse of the bulk modulus used in the geomechanical model, which yields compressibilities of $1.50 \times 10^{-4} \text{ psi}^{-1}$ and $1.50 \times 10^{-6} \text{ psi}^{-1}$ for the reservoir and non-pay regions, respectively.

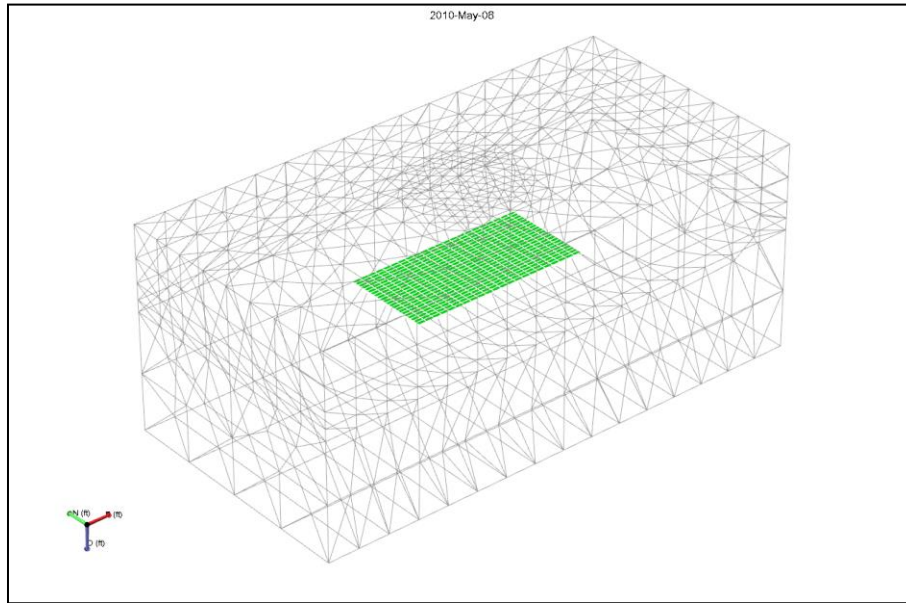


Figure 1: Our implementation of the Dean et al. (2006) model. The solid small region in the centre is the reservoir simulation grid. The FE-Mesh is shown as transparent and in grey. It has an additional underburden compared to the Dean et al (2006) paper, but is kept immobile during the benchmark simulations.

2.1.3 Alternative Model Set-up

In addition to simulations with the benchmark parameters as specified in Dean et al. (2006), simulations were performed with more realistic rock mechanical properties for actual hydrocarbon reservoirs, using the same mesh and grid set up. In the more realistic scenario, additional underburden in the FE-Mesh (14,750 ft, resulting in a total FE model thickness of 25,000 ft) was active in the simulation. In addition, the Young's modulus is set to 2.5×10^6 psi within the reservoir and 3.0×10^6 psi in the non-pay zone. This yields in-situ compressibilities of 6.0×10^{-7} psi⁻¹ and 5.00×10^{-7} psi⁻¹ for the reservoir and non-pay zones, respectively.

2.2 Two-way Coupling between the Reservoir Model and the Geomechanical Model

After creating both independent models, the next step comprises coupling the models in an iterative manner. To be able to do the coupling the following steps are necessary (Figure 2):

- 1) Map the results from the reservoir model onto the geomechanical model,

- 2) Run the geomechanical model with the new pore pressure,
- 3) Map the calculated strains from the geomechanical model to the reservoir model,
- 4) Update the reservoir model by recalculating the porosities, permeabilities, pressures and compressibilities based on the deformations from the geomechanical model,
- 5) Run the reservoir model to obtain the next pore pressure, and
- 6) Start at 1) again for the next time iteration.

In the following we will discuss the steps above in more detail.

2.2.1 Mapping

Abaqus and IMEX use different discretizations. The geomechanics grid is discretized into a finite element mesh where the displacements are computed at the corners and the stresses are computed at the Gaussian points. IMEX is discretized into a finite difference grid where the flow variables are computed at the center of the grid cell. In addition to coupling the governing equations, it is necessary to formulate an algorithm for exchanging and mapping between the finite element mesh and the reservoir grid. When mapping a reservoir grid to a finite element mesh, the first step is to determine the nodal location of the finite elements with respect to the reservoir grid. To transfer pressure and temperature properties to the node, it must lie within the reservoir grid. The second step is to determine which reservoir grid cells have their center located inside of a finite element.

In the presented workflow, a dedicated subsurface modeling package (JewelSuite Subsurface Modeling™) is used where a dedicated workflow can map properties from a grid to a mesh and vice versa. In this two-way coupled study, there are two methods that can be used to map the properties from the finite difference grid to the finite element mesh and vice versa: mapping by the nearest neighbor and linear least squares interpolation. The easiest assessment of a two-way coupled system has coincident finite elements on the reservoir grid cells as in the current set-up. However, it should be noted that the very elongated, thin finite-difference cells in the reservoir model don't have well-suited length thickness ratios for finite element modeling. To avoid numerical issues, it is recommended to investigate if the vertical cell stacks in the reservoir model can be lumped into a finite element, or if the lateral extent of the reservoir grid cells can be reduced to create better finite elements.

2.2.2 Porosity Update

When coupling the simulators, it must be taken into account that both simulators use various approaches to track the porosity changes and available mass in the model. Therefore, careful considerations are needed to make sure that production, pore pressure changes and cell deformations do not lead to any mass loss or gain in the total system while using the iterative-coupled scheme. To couple Abaqus to IMEX, updating initially set parameters such as the reference porosity is the best solution to maintain mass balance. The following scheme is used to recalculate these set parameters.

In the finite element mesh of the geomechanical model, the bulk volume is related to changes in the volumetric strain of the elements as in Equation (1).

$$V_b^{GS} = V_b^n (1 - (\varepsilon_{vol}^{n+1} - \varepsilon_{vol}^n)) \quad (1)$$

where V_b^{GS} is the bulk volume of a geomechanical time step, V_b^n is the bulk volume of the element at the previous time-step, ε_{vol} is the volumetric strain at the next iteration (n+1) and current iteration (n).

The pore volume within a geomechanical simulation is related to the bulk volume as in Equation (2).

$$V_p^{GS} = V_b^{GS} - V_s^0 \quad (2)$$

where V_p^{GS} is the pore volume of the geomechanical step and V_s^0 is the solid volume of the element.

The porosity of any given geomechanical step is calculated as in Equation (3).

$$\Phi^{GS} = \frac{V_p^{GS}}{V_b^0 \cdot NtG} \quad (3)$$

where Φ^{GS} is the porosity at the geomechanical step and NtG is the sand-to-total volume ratio of the element (Net to Gross).

In conventional reservoir simulators such as IMEX used in this workflow, the porosity varies with pore pressure in a linear fashion depending on the compressibility of the rock, as in Equation (4).

$$\Phi^{n+1} = \Phi^n [1 + c_r (p^{n+1} - p^n)] \quad (4)$$

where Φ is the cell porosity, p is pressure, c_r is the cell compressibility and n is the time-step iteration.

Within the reservoir grid cells, the porosity is assumed to be based on a fixed bulk volume, as in Equation (5).

$$\Phi_{res} = \frac{V_p}{V_b^0} \quad (5)$$

where Φ_{res} is the porosity of the reservoir grid cell, V_p is the volume of the pores within the grid cells and V_b^0 is the fixed bulk volume of the cell (assuming no deformation or displacement of the boundaries of the given grid cell).

The pressure-dependent porosity of the flow simulator is given by Equation (6).

$$\Phi^{FS}(P) = \Phi_{ref}(1 + c_r^{FS} \cdot \Delta P) \quad (6)$$

Because of the geomechanical changes in the system, the porosity changes in the system are dependent on the pressure depletion path. The reference porosity is the porosity within each cell at a given pressure. Over the course of the simulation with geomechanical effects incorporated, the pressure and porosity at n+1 of a two-way coupled simulation will differ from the pressure and porosity at n+1 of a flow-only simulation. The reference porosity is taken to be the corrected pressure-dependent porosity mapped back from the geomechanical simulation to start the next flow iteration (at the pressure that the porosity was corrected to).

In the iterative process, the porosity must be updated when reading files of the flow simulator at each time step, because of the geomechanical changes in stress at the time step. Therefore, the reference pressure must also be updated with the porosity in each reference cell. The updated reference porosity is determined in Equation (7):

$$\Phi_{ref}^{GS} = \frac{\Phi^{GS}}{1 + (c_r^{FS} \cdot \Delta P)} \quad (7)$$

where Φ_{ref}^{GS} is the reference porosity from the geomechanical simulator, c_r^{FS} is the rock compressibility used in the flow simulator, and ΔP is the change in pressure between iterations within the reservoir simulation.

The bulk volume is fixed in the reservoir simulation, therefore the corresponding geomechanical-corrected pore volume for the reservoir cell is given by Equation (8):

$$V_p^{FS} = V_b^0 \cdot NtG \cdot \Phi^{FS}(P) \quad (8)$$

Since the above calculations can change the reference porosity in each cell of the reservoir simulator, a correction to the reservoir pressure and actual saturations may be necessary to maintain the correct mass balance in the system.

A flash calculation is performed within each reservoir cell at the appropriate pressure and temperature to determine the masses of the various components within the cell at the pore pressure and temperature of that reservoir cell.

Additionally, depending on the thermodynamic state of the system and the fluid compressibilities, a volume balance on the phases within the pores is computed using the masses of the individual components. The pressure-dependent, volume-balance porosity is given in Equation (9):

$$\Phi^{VB}(P) = \Phi_{ref}^{GS}(1 + c_r^{FS}(P^{VB} - P^0)) \quad (9)$$

where $\Phi^{VB}(P)$ is the volume-balanced porosity based on the PVT properties of the system, and P^{VB} is the pressure of the system at the appropriate reservoir temperature.

The pressure is corrected to account for fluid compressibility as specified in the PVT properties of the fluids within the reservoir simulator and the appropriate volumes are validated against the flash calculations at the given pressure and temperature of the reservoir system.

In addition to the porosity update, the modeler may specify the relationship between changes in the pore volume of the reservoir cells and the corresponding changes in permeability. However, in the benchmark model, the permeability is assumed to be constant and independent of the porosity.

2.2.3 Pseudo-Compressibility Updates

A realistic reservoir may be sensitive to stress changes from changes in pressure, temperature and production within the reservoir zone which, in turn, leads to nonlinear geomechanical effects and potential stress arching. Through rearranging of Equation (4) and solving for the compressibility, the ratio of pressure change to changes in porosity can be obtained with respect to the limitations of compressibility, as in Equation (10). Compressibility is the only parameter available in reservoir simulation to account for the geomechanical effects:

$$c_r = \frac{\phi^{n+1} - \phi^n}{\phi^n (p^{n+1} - p^n)} \quad (10)$$

where c_r is the compressibility, Φ is the porosity of the cells from the flow step, p is the pressure, n is the current iteration and $n+1$ is the next iteration.. Changes in the volumetric strain within reservoir grid cells (relative to a fixed bulk volume) are taken as the change in porosity for a given reservoir cell. Making this substitution and realizing that Φ^n is the initial porosity within a reservoir grid cell of fixed bulk volume, Equation (11) for the pseudo-compressibility is obtained.

$$c_{pseudo} = \frac{\varepsilon_v^{n+1} - \varepsilon_v^n}{\Phi^0 (p_i^{n+1} - p_i^n)} \quad (11)$$

where ε_v is the volumetric strain and Φ^0 is the initial porosity within the reservoir grid cell.

To obtain the change in volumetric strain (numerator in the above Equation (10)) a geomechanical simulation is run after importing the changes in pressure from a reservoir simulation (denominator in Equation (10)).

In addition to the reference porosity update presented in the previous section 2.2.2 , for better convergence and results, the pseudo-compressibility coupling parameter (which accounts for the volumetric deformation of the rock) must be updated every time step in the flow simulator. Additionally, before the system is simulated in a coupled fashion, an empirical model of pseudo-compressibility is derived using the initial bulk modulus and the corresponding sensitivity to production rates and pressure changes within the reservoir. The initial compressibility of each reservoir cell is calculated as the inverse of the bulk modulus of the rock.

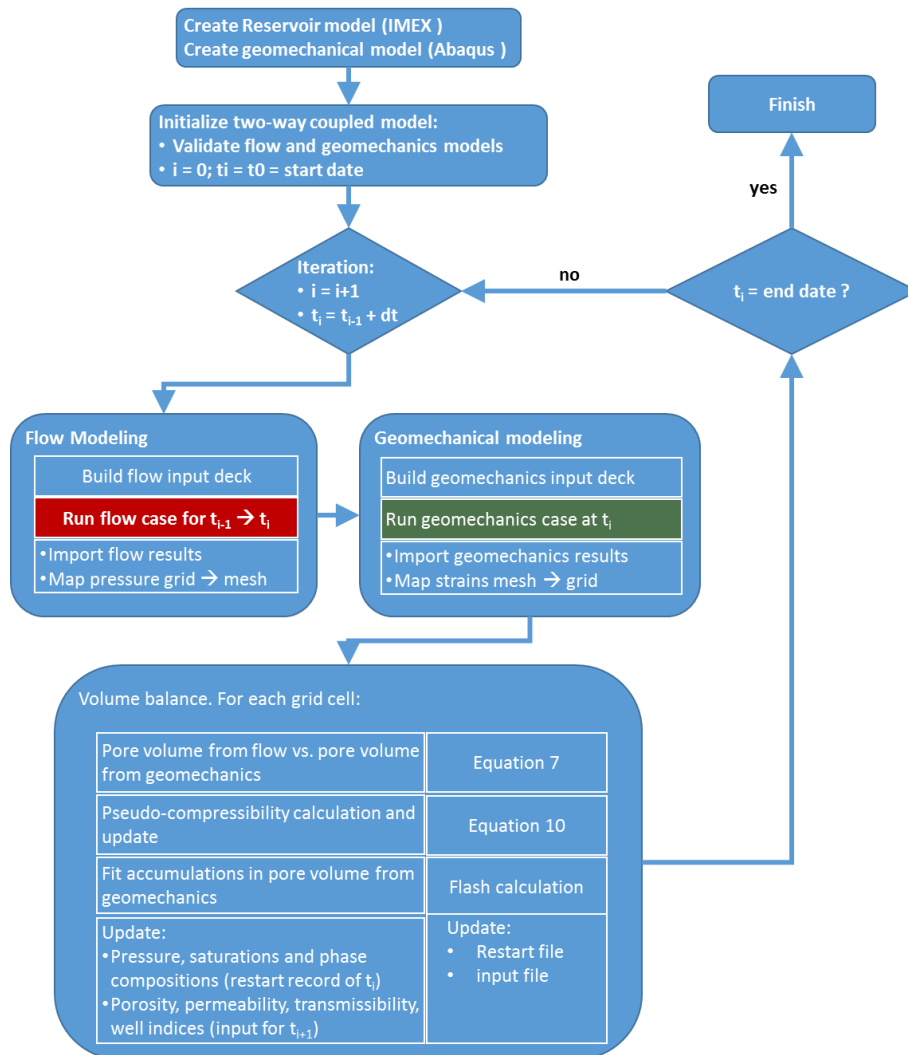


Figure 2: Flow diagram of the two-way coupled workflow. The red cell represents the IMEX simulator, and the green cell represents the Abaqus simulator. The blue boxes are the coupling through the JewelEarth platform.

2.2.4 Time Stepping

The time steps in the reservoir model and the geomechanical model are differently spaced. The reservoir model needs a much smaller time stepping because of the nature of the finite difference modeling used. The steady-state finite element modeling allows for larger time steps.

The presented workflow uses a pre-determined time stepping for the coupling between both models. This means that normally the reservoir model performs a couple of time steps before a coupling is made with the geomechanical model. After the pore pressures of the reservoir model are mapped on the geomechanical model, a restart file is created for the Abaqus model only containing a steady state *soils step with the updated pore pressure as a boundary condition.

After the Abaqus model finishes the volumetric changes are mapped to the reservoir model and the pore pressure and other updates are calculated (as described in sections 2.2.2 and 2.2.3). Then the reservoir model is restarted using the updated restart and input files.

3. Results and Discussion

The subsidence results from the explicitly two-way coupled benchmark model are compared with the results as presented in Dean et al. (2006), and a one-way coupled model in Figure 3Figure 1.

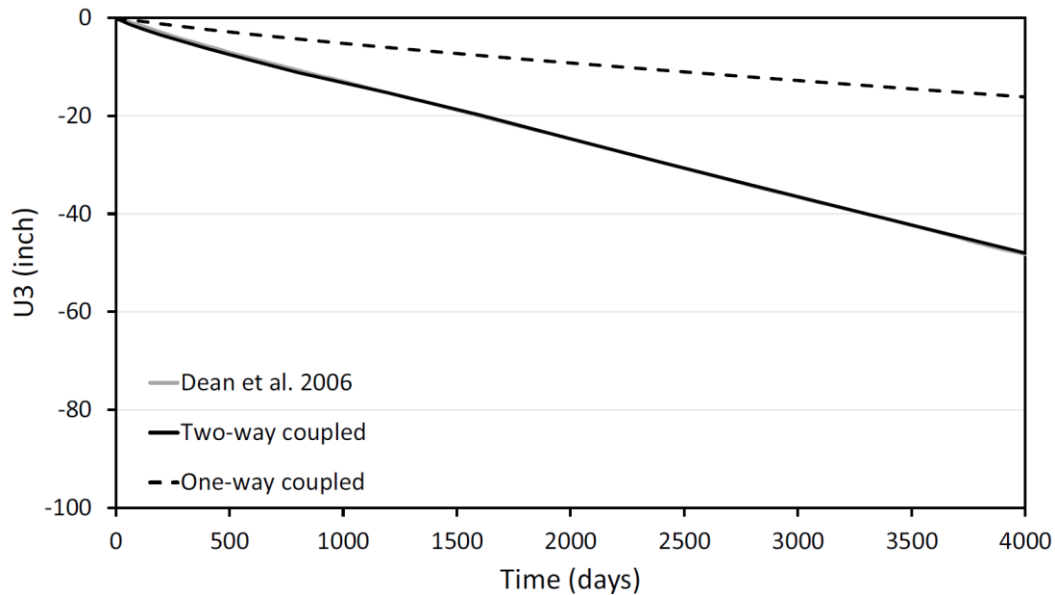


Figure 3: Subsidence at the surface – with pseudo-compressibility updates. Comparison between results from Dean et al. (2006) paper (solid gray line), the new two-way coupled simulation (solid black line), and one-way coupling on the same model (dashed black line).

Figure 3 shows the results satisfactorily match the subsidence at the surface to the benchmark model. It was discovered that the minimum time step at which the model was explicitly coupled that achieved a close fit with the validation model was every 20 days. Any time steps smaller than 20 days did not add any noticeable value to this model with respect to accuracy of the subsidence curve obtained, and increased computational time.

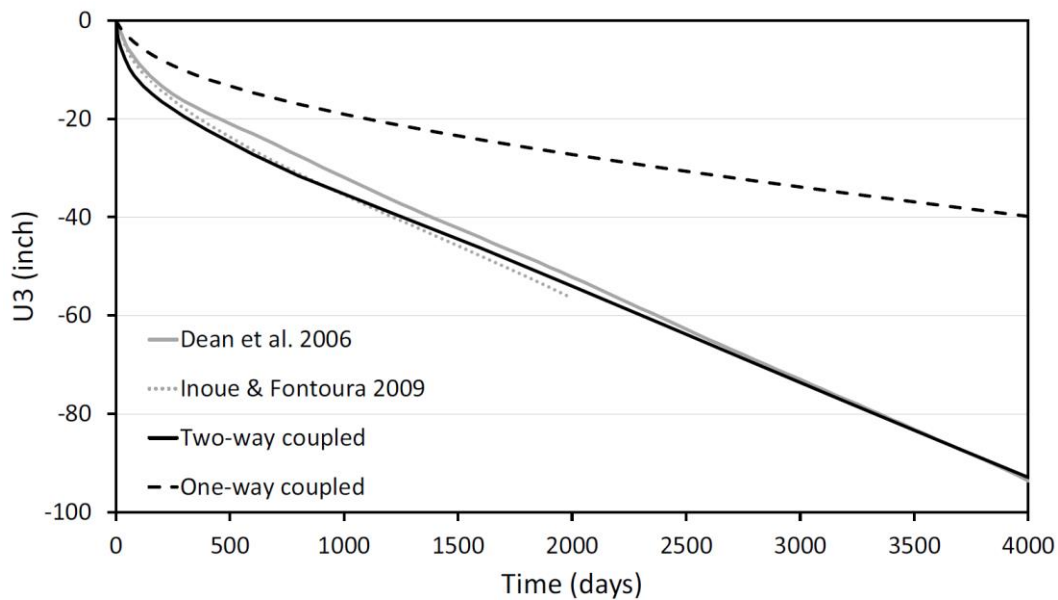


Figure 4: Subsidence at top of the reservoir – with pseudo-compressibility updates. Comparison between results from Dean et al. (2006) paper (solid gray line), Inoue and Fontoura (2009) paper (dotted gray line), the new two-way coupled simulation (solid black line) and one-way coupling on the same model (dashed black line).

Figure 4 shows the subsidence of the reservoir zone (at 10,000 ft.) matches satisfactorily with the validation model with a total subsidence of >90 in after 4,000 days of production. From the beginning of the simulation through 2,000 days of simulation time, the subsidence is slightly greater (5 to 6%) for the benchmark model than in the Dean et al (2006) paper. In the Dean et al. (2006) paper, the coupling was performed every 20 days for 400 days and increased to 400-day increments after that.

3.1 Effect of Pseudo-Compressibility Update

Careful investigation of the pressure and porosity curves shows that the system overcorrects the porosities and pressures causing irregular subsidence rates. To increase the accuracy of the new model, a pseudo-compressibility update was utilized over the course of the explicitly coupled 20-day time increments. The pseudo-coupling used in the example adds more accuracy because the appropriate volumetric strains are accounted for during the 20-day periods, which enables for a greater correction to the porosity obtained and are sent to the reservoir simulator (Figure 5).

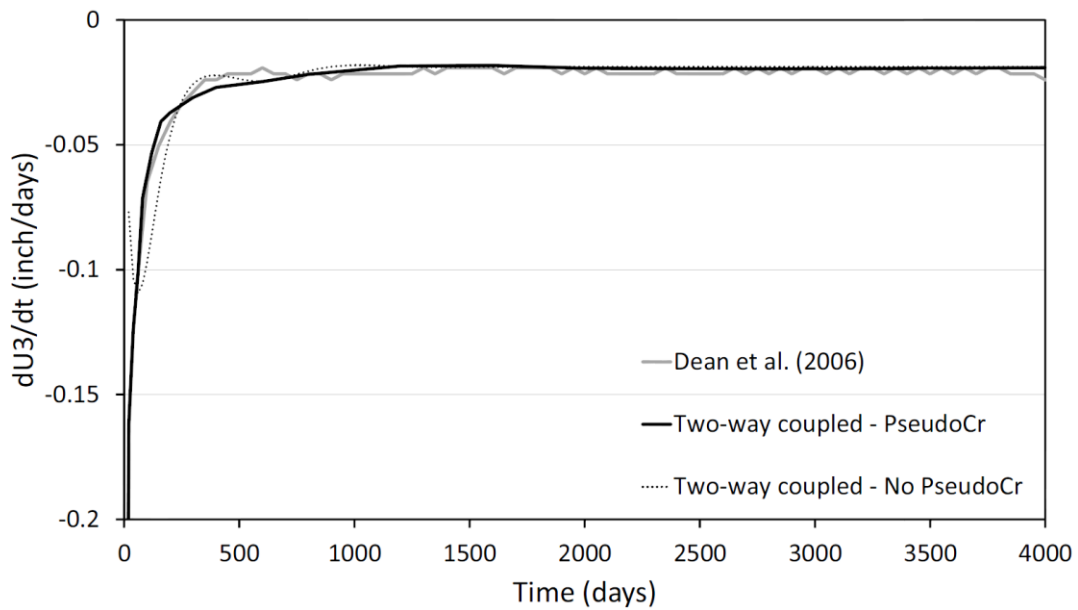


Figure 5: Derivative of subsidence at top of the reservoir. The figure shows the difference between applying and not applying pseudo-compressibility updates, and compares these to the results of Dean et al. (2006) (solid gray line). The model without pseudo-compressibility updates (dotted black line) shows inconsistent rates of subsidence (overshoots and corrections) caused by a poor match between actual geomechanical results and the estimate used in reservoir modeling. The model with pseudo-compressibility updates (solid black line) is more consistent, starting with the largest rate of subsidence which gradually changes into a constant rate.

3.2 Effect of More Realistic Mechanical Parameters

To assess if two-way coupling adds to the accuracy of subsidence calculations, a model with more realistic rock mechanical parameters was built. Figure 6 shows that the subsidence at the top of the reservoir zone (10,000 ft) is much less extreme. It even shows that in the case of higher Young's modulus with a larger underburden (which adds stability to the sideburden's surrounding the reservoir), there is little difference between one-way coupled and two-way coupled results.

Comparisons between the Dean et al. (2006) and the more realistic scenario show the importance of reservoir assessment and the potential need for two-way coupled modeling in highly stress-sensitive reservoirs, when compared to one-way coupling. In addition to the Dean et al. (2006) model, it is important to assess the effect that critically stressed natural fractures and faults have on the coupling of reservoir and geomechanical modeling, and the necessity, if any, for two-way coupled modeling.

Additional reservoir shapes and settings are also under investigation, but are beyond the scope of this paper.

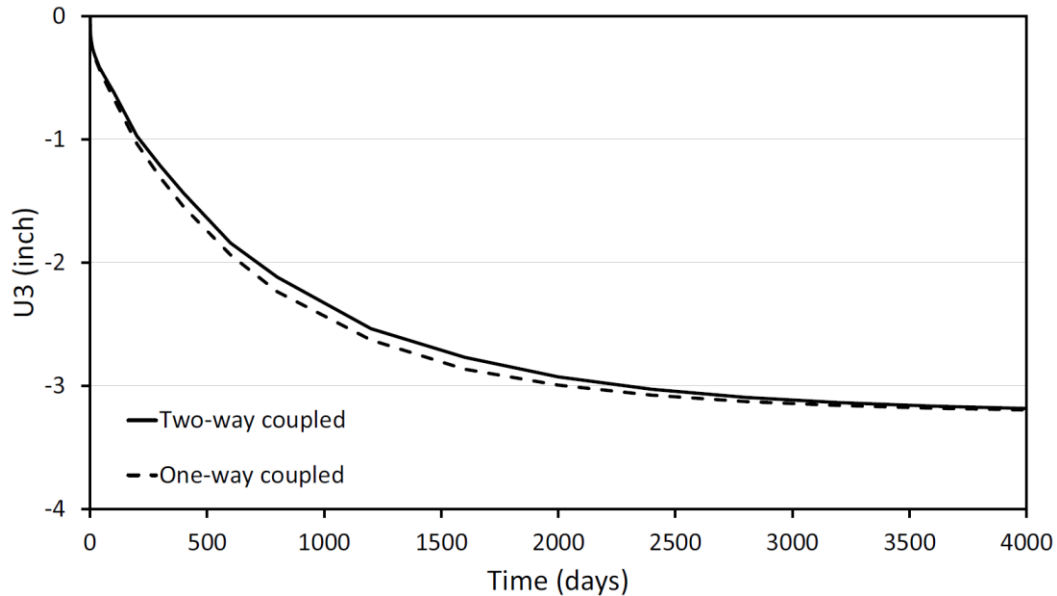


Figure 6: Subsidence at top of the reservoir for a case with much more realistic geomechanical properties and with pseudo-compressibility updates. The difference between two-way (solid black line) and one-way (dashed black line) coupling is much smaller than in the original benchmark models, and total subsidence is much less extreme.

4. Conclusions

A workflow was developed that efficiently couples two-way IMEX reservoir simulation and Abaqus geomechanical simulation through the JewelEarth platform. The results compare well with a published benchmark model.

Additional accuracy was included by utilizing a pseudo-compressibility update that accounts for all volumetric strains based on pressure drop over an explicitly given coupled time step within the individual cells.

A model with more realistic mechanical parameters shows that a two-way coupled scheme doesn't add much to subsidence calculations compared to a one-way coupled scheme. However, for very stress-sensitive reservoirs and a high contrast in stiffness between the reservoir and surrounding formations, the two-way coupled workflow might have a profound effect on the reservoir model and calculated subsidence.

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