Three-way coupling of compositional flow and poromechanics in porous media

Xueying Lu† and Mary F. Wheeler†

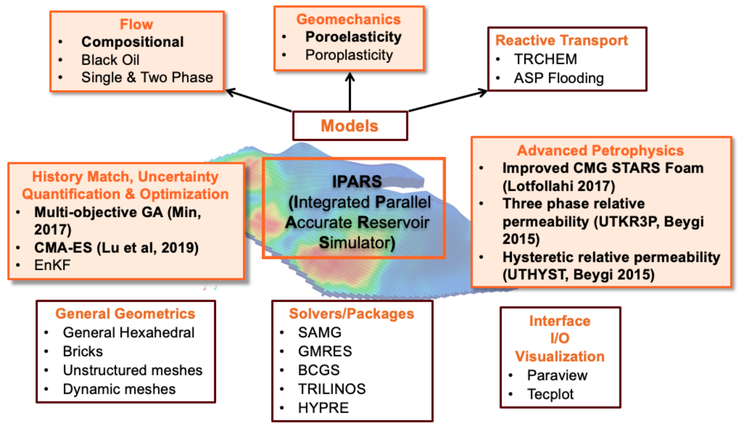
†Center for Subsurface Modeling, Oden Institute for Computational Engineering and Sciences, University of Texas at Austin

{xueying,mfw}@oden.utexas.edu

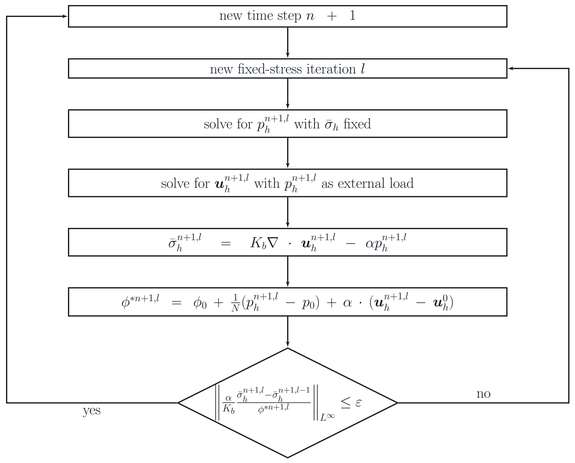
Highlights

We present a three-way coupling algorithm for both single phase flow and compositional flow coupled with linear poroelasticity [1] . An error indicator is calculated at each flow time step to determine when displacement must be updated and whether fixed-stress iterative coupling technique is required. Convergence of the three-way coupling is established by extending previous work on a priori analyses of fixed-stress iterative coupling [2]. Numerical results for Mandel's problem confirm these theoretical results for single phase flow. Numerical results for coupled compositional flow and geomechanics simulations for field-scale CO_2 sequestration and surfactant-alternating-gas (SAG)-assisted CO_2 sequestration achieve a substantial reduction in mechanics update times for 99.4% and 97.5%, respectively.

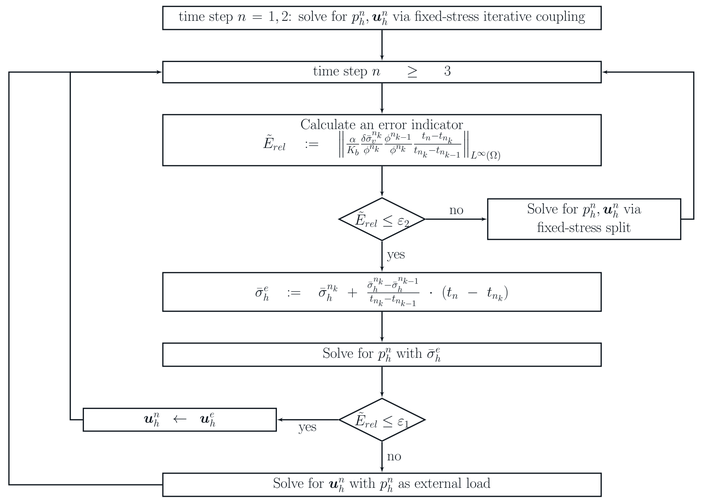
The Simulator IPARS



Fixed-Stress Split



Three-Way Coupling



Mandel's Problem

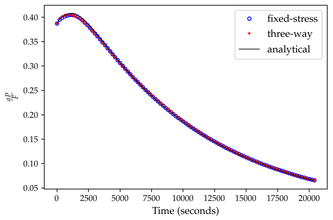


Fig. 1: Pressure solution at the cell-center closest to the origin

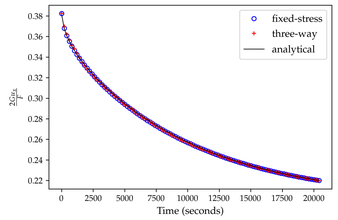


Fig. 2: x-displacement at the free end $x = a$

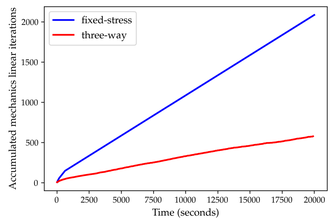


Fig. 3: Accumulated number of geomechanics linear iterations comparison

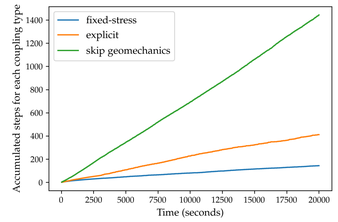


Fig. 4: Accumulated time steps for each coupling type during three-way coupling

$\mathcal{T}_h$	$\left\| \frac{1}{\Delta t}(p_h - P_h p) \right\|_{L^\infty(L^2)}$	Rate
60×60	0.3280E-02	-
80×80	0.2579E-02	0.8359
100×100	0.1727E-02	1.2361

Fig. 5: Numerical convergence of pore pressure via three-way coupling for the Mandel's problem.

CO_2 Sequestration at Cranfield

Continuous CO_2 Sequestration

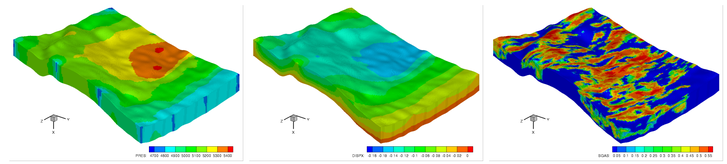
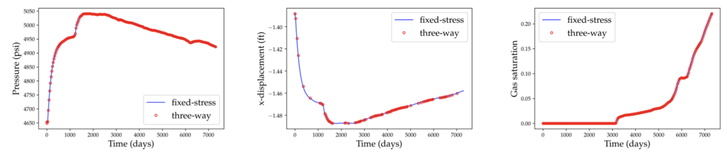


Fig. 6: Simulation results of continuous CO_2 sequestration via three-way coupling at the end of 20 years.



(a) pressure solution (b) x-displacement solution (c) gas saturation solution

Fig. 7: Simulations of continuous CO_2 sequestration via fixed-stress iterative coupling and three-way coupling.

Technique	Time steps	Flow model time (s)	Mechanics model time (s)	CPU time (s)
Fixed-stress	94494	36068	181299	217368
Three-way	84168	31852	**1030**	32883

Fig. 8: Run time comparison for different coupling techniques for continuous CO_2 sequestration.

SAG-Assisted CO_2 Sequestration

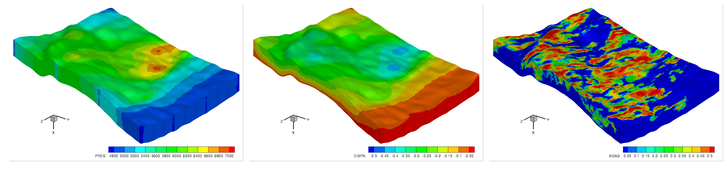
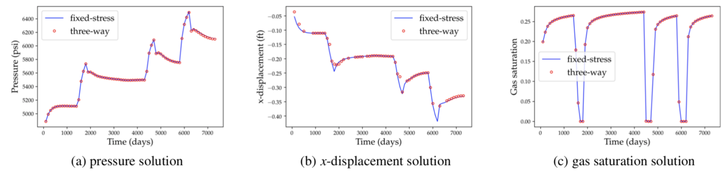


Fig. 9: Simulation results of SAG-assisted CO_2 sequestration via three-way coupling at the end of 20 years.



(a) pressure solution (b) x-displacement solution (c) gas saturation solution

Fig. 10: Simulations of SAG-assisted CO_2 sequestration via fixed-stress iterative coupling and three-way coupling.

Technique	Time steps	Flow model time (s)	Mechanics model time (s)	CPU time (s)
Fixed-stress	142937	65496	262636	328133
Three-way	141152	64969	**6633**	71603

Fig. 11: Run time comparison for different coupling techniques for SAG-assisted CO_2 sequestration

References

[1] X. Lu, and M. F. Wheeler. "Three-way coupling of multiphase flow and poromechanics in porous media." Journal of Computational Physics (2019): 109053.

[2] V. Girault, M. F. Wheeler, T. Almani, S. Dana, A priori error estimates for a discretized poro-elastic–elastic system solved by a fixed-stress algorithm, Oil & Gas Science and Technology-Rev. IFP Energies nouvelles 74 (2019) 24.