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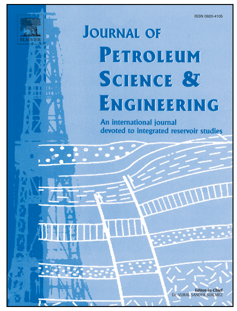

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Gradient-based constrained well placement optimization

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Abstract

A novel well placement gradient approximation methodology is developed based on performing finite difference approximations of augmented Lagrangian derivatives within the adjoint formulation. The methodology is efficient because it requires only a pair of (forward and backward) simulations to yield a cost function sensitivity with respect to well placement coordinates. The approximated derivative is used within a Sequential Quadratic Programming (SQP) solver ensuring fast convergence and efficient constraint-handling. An extensive error analysis is performed to identify the gradient approximation errors associated with different perturbation ranges. This analysis provides information regarding the appropriate perturbation step size range needed to maintain a consistent gradient approximation while reducing errors associated with the simulation and the discretized nature of the reservoir. We validate the efficiency of the approach by solving for optimal well placement and comparing the results against two major gradient-based well placement approaches from the literature. For these cases, the methodology developed in this work delivers higher or similar final objective values while providing better performance in terms of fewer cost function evaluations. Finally, the methodology is used to find the optimal configuration of multiple deviated producers both in a binary channelized case and in a case based on the Brugge reservoir. These applications show that the proposed methodology can handle cases with more complex grid and production scenarios that require derivative information for the location of deviated wellbores in continuous space.

Keywords: Optimal well placement, Gradient-based optimization, Adjoint-based gradient, Single-segment deviated wellbores, Inter-well distance constraint, Well-to-boundary distance constraint

1. Introduction

In this work, we present a novel and efficient way to approximate derivative information with respect to well location. The proposed approach relies on an augmented Lagrangian approximation of the cost function provided by an adjoint formulation. Within the adjoint framework, the approach evaluates the gradient of the objective using finite differences. This yields an inexpensive gradient assembly procedure that produces a well placement gradient after only two simulations, i.e., one forward- and one backward-in-time. Specifically, this approach extends the application of the adjoint gradient framework to well location variables, which typically lack a continuous representation within the reservoir model. Crucially, the ability to estimate the sensitivity with respect to wellbore location in an efficient manner enables the use of gradient-based routines for optimization of complex wellbore designs and configurations.

Despite being local, gradient-based techniques are efficient, rely on well-established convergence theory, and can be implemented in a straightforward manner by making use of a variety of off-the-shelf solvers. These techniques are therefore attractive to use for the well placement problem. In this work, we couple the approximated gradient with a Sequential Quadratic Programming (SQP) method.

The gradients obtained by the proposed methodology depend on the accuracy of the finite difference approximation of the adjoint partial derivative terms. Clearly, to perform an efficient well placement local search, it is important that these gradients are consistent and sufficiently accurate. For

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