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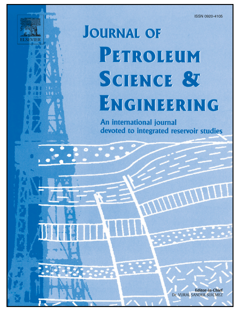

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Non-distance-based Localization Techniques for Ensemble-Based Waterflooding Optimization

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Abstract: The problem of determining life-cycle rate controls for both producer and injector wells that maximize the net present value subject to well and field-wide capacity constraints is solved using an SQP algorithm. The required gradient is approximately computed by an ensemble-based method. Refinement techniques are employed to mitigate deleterious effects of spurious correlations and to improve the overall optimization efficiency.

Control variables are rates of each well completion assumed independently controlled. Field NPV is decomposed as the sum of the NPV's of each well. Sensitivity matrix of well NPV's with respect to controls of all wells is obtained from ensemble-based covariance matrices of controls and of well NPV's to controls. For efficiency reasons ensemble size should be kept small which results in sampling errors. Since covariance matrixes are plagued with spurious correlations, regularization and novel non-distance-based localization techniques are required to improve the quality of the resulting sensitivity matrix. The effective approximate gradient is the sum of the columns of the refined sensitivity matrix.

Three realistic reservoirs taken from the literature are used to demonstrate the efficiency of the refinement techniques. Realizations are generated from optimization iterates by adding temporally correlated random perturbations. Realizations go through a scaling procedure that ensures feasibility of all ensemble members. At the start of the optimization process simulation results of ensemble members are used to compute inter-well connectivities using a Producer-based Capacitance Resistance Model (CRMP) and competitiveness coefficients between producers using an Interference Test. Sensitivity of producer NPV's with respect to injector well controls are refined through a novel localization technique based on the connectivity of each injector/producer pair. Sensitivity of producer NPV's with respect to producer well controls is regularized by competitiveness coefficients keeping the coefficients of each well with respect to its own controls and weight averaging the effects of other producer well controls. Sensitivity of injector NPV's with respect to controls of producer and other injection wells are regularized depending on the actual realization of input injection rate controls by the simulator during control steps. NPV gains up to 15% of the average NPV values in twenty runs are obtained with much reduced scatter in comparison with solutions without refinement.

The proposed regularization and novel non-distance-based localization techniques for refinement of the sensitivity matrix in ensemble-based waterflooding optimization, which automatically detects sealing faults and regions of low permeability, results in significant gains in NPV values and reduction in their variability. The added numerical cost is insignificant as previous simulation results are reused. The simulator is treated as a black-box in the optimization process and actual production history may be used in the localization criterion.

Keywords: Waterflooding Optimization; Ensemble-based methods; Sensitivity refinement; Constrained Optimization

1. Introduction

In reservoir engineering one of the main objectives is the development of optimization techniques to increase the profitability of an asset. The usual merit function is the Net Present Value (NPV) which evaluates the discounted cash flow of the field operation. Waterflooding is the most commonly used method to enhance oil recovery. The injected water helps maintaining reservoir pressure and increasing sweep efficiency. A frequent problem in waterflooding is early water breakthrough in producing wells which can be delayed by better managing the advance of the water front through convenient rate control.

The objective of this work is to determine the rates for producer and injector wells along the life-cycle period that maximize the NPV subject to constraints at well and field levels using the Sequential Quadratic Programming algorithm (SQP). Constraints are imposed to ensure the feasibility of the solution with respect to capacity of well and surface equipment. The most efficient optimization techniques require computation of gradients of involved functions with respect to control variables.