Robust optimization of Oil reservoir water-flooding

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1 Introduction
Model-based dynamic optimization of oil production has a significant potential to improve the economic life-cycle performance [1]. But due to the limited knowledge of geological model parameters such model-based optimization suffers from high level of uncertainties. Because of this uncertainty, the long term predictions of these models are also highly uncertain. Therefore, in order to steer the solution in the attractive direction of optimal economical profit with respect to both short-term and long-term, including model uncertainty in the economic optimization problem is desirable. Different (ad-hoc) methods have been proposed e.g., [2] to balance short-term and long-term objectives. In this work, we intend to show that by properly handling model uncertainty in the (robust) optimization problem an appropriate balance between these economic objectives is naturally obtained.

2 Water-flooding Optimization
Water flooding, a common technique used in oil recovery, makes use of injection and production wells. The production wells are used to transport liquid and gas from the reservoir to the surface and the injection wells are used to keep the pressure difference by injecting water and pushing oil towards production wells. The objective of the water-flooding optimization is to maximize a simple Net Present Value (NPV) of the cumulative oil and water production over a fixed time horizon. Thus searching for an optimal control strategy to manipulate (to some degree, through injection and production valves) the progression of the oil-water front in order to maximize oil recovery.

3 Robust Optimization
A common approach to determine the effect of modeling uncertainty, is to create a set of possible realizations of the reservoir model. The finite set of realizations is created in such a way that it gives a discretized approximation of the uncertainty space associated with the modeling process of the real oil reservoir. Within Robust optimization, the set of realizations may be used in various ways to account for the effect of uncertainty. One of the straightforward robust optimization objectives is using the average outcome over the set of realizations [3]. In this work, an average NPV is optimized which is represented by the robust objective function $J_{rob}$ as shown below:

$$J_{rob} = \frac{1}{N_r} \sum_{i=1}^{N_r} J(u_{1:K}, \theta_i)$$

Here $J(.)$ is the NPV cost function, $N_r$ is the number of model realizations, $\theta_i$ is the discretization of parameteric uncertainty space and $u_{1:K}$ is the controlled input sequence.

4 Simulation Example
The robust optimization procedure is based on a set of 100 realizations of the standard Egg model, a 3-dimensional petroleum reservoir model, which leads to a control strategy that explicitly accounts for geological uncertainty. The permeability field and well locations of the first realization of the set are depicted in Fig. 1. A gradient-based optimization procedure is used to obtain a (possibly local) optimal solution in which the gradient information is computed by solving a system of adjoint equations. The 100 realizations reflects the range of possible geological structures which honor the statistics of the modeling uncertainty.

Figure 1: Permeability field and well locations of Realization Number 1 of a set of 100 realizations.

References