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Reza Yousefzadeh · Alireza Kazemi · Mohammad Ahmadi · Jebraeel Gholinezhad

Introduction to Geological Uncertainty Management in Reservoir Characterization and Optimization

Robust Optimization and History Matching

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This book is dedicated:

To my wonderful friend, Meysam Yari, and my family that always supported me.

Reza Yousefzadeh—January 2023

Preface

The main purpose of this book is to investigate the methods, challenges, and solutions to manage uncertainty in reservoir characterization and optimization. This book is a quick and strong introduction to reservoir characterization and optimization under geological uncertainty that can guide graduate/post-graduate students and researchers to start their investigations with a strong understanding of the basics of geological uncertainty and solutions to it. The content of this book is prepared based on the most prominent works by a large number of authors including the authors of this book who have had several published works regarding the geological uncertainty management both in reservoir characterization and in optimization. Since this book is a brief, methods and examples are briefly described and some outdated methods are ignored.

This book contains five chapters. In Chap. 1, types and sources of uncertainty, uncertainty in different reservoir management phases, and challenges in those phases are introduced, and general methods to manage those uncertainties are explained. Chapter 2 is about the “Geological Uncertainty Quantification”. This type of uncertainty is related to macro- (e.g., fluid contacts) and micro-scale (e.g., permeability distribution) parameters that affect all decisions about field development. Use of geological prior information, seismic and petrophysical data, geological parametrization, and exploring the range of scenarios are explained in this chapter. Then, geological realizations and methods to generate them are explained; their workflow, advantages, and disadvantages are discussed. Chapter 3 is dedicated to “Reducing the Geological Uncertainty by History Matching”. History matching suffers from different challenges including high dimensionality of the models, nonlinear, non-Gaussian, and three-dimensional distribution of the uncertain parameters, which are introduced in this chapter. In the end, different approaches to history matching, including the open-loop and closed-loop reservoir management as well as the common methods of history matching, are described; their advantages and shortcomings are discussed. In Chap. 4, dimensionality reduction methods to resolve the challenges related to high dimensionality of the geological realizations are presented. Dimensionality reduction methods proposed by the authors of this book and others, including the conventional and novel machine learning-based methods, are presented, and their pros and cons are discussed. Chapter 5 is about “Field Development Optimization Under Geological Uncertainty” using robust optimization. Challenges in robust field development optimization, including the high computational cost, risk attitudes, and choosing a subset of realizations to use in robust optimization, are discussed, and common solutions are introduced. In this regard, recent methods of selecting a subset of realizations using static, dynamic, and hybrid properties of the reservoir in green and brown fields and novel approaches to constraining the search space of the optimizers to facilitate the robust optimization process proposed by the authors and other researchers are presented. In the last chapter (Chap. 6), different kinds of proxy models in history matching and robust field development optimization are introduced. These proxies include the physics-based, non-physics-based, and hybrid proxies. Their pros and cons are discussed, and some of their applications in history matching and robust optimization are presented.

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Chapter 1
Uncertainty Management in Reservoir Engineering

Abstract Almost all activities in real life entail different kinds of uncertainty. From daily decisions to complicated problems, such as petroleum reservoir characterization, suffer from uncertainties. Uncertainty can have different roots, including incomplete observation of the system, incomplete modeling of the system because of our limited knowledge and understanding of the underlying mechanisms and rules of the system, intrinsic uncertainty in the system, and inaccurate measurement of the system's parameters. The first step to deal with uncertainty is to recognize its root and type. This chapter introduces different types of uncertainty in reservoir engineering, challenges induced by uncertainty, and common ways to treat them. Two general approaches to handle the uncertainty are described, named forward uncertainty management and inverse uncertainty management. Forward uncertainty management tries to propagate the uncertainty from inputs to the output(s) to make robust decisions regarding the problem understudy. On the other hand, inverse uncertainty management deals with calibrating model parameters to reduce the range of uncertainty.

Keywords Uncertainty · Reservoir engineering · History matching · Robust optimization · Bayesian framework · Geological uncertainty · Field development

1.1 Introduction to Uncertainty Management in Reservoir Engineering

Uncertainty is present in almost all kinds of activities and processes. In fact, except for simple mathematical expressions, it is very hard to find an event that is completely true or that will happen deterministically [1]. This uncertainty increases the complexity of problems. For example, if a decision is made under some assumptions without considering the uncertainties, it may fail if the conditions turn out to be different from that of thought to be. This can yield instability in the decision making process. As a result, any decision making process should consider the uncertain nature of events, and the decisions should be made under the present uncertainties. Consequently, the decision will be stable if the situation changes.

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